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HANDBOOK OF PROCEDURES FOR ESTIMATING COMPUTER SYSTEM SIZING AN--ETC(U)

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HANDBOOK OF PROCEDURES FOR ESTIMATING COMPUTER SYSTEM SIZING AND TIMING PARAMETERS

Volume II: Addendum

Doty Associates, Inc.
416 Hungerford Drive
Rockville, Maryland 20850

15 February 1980

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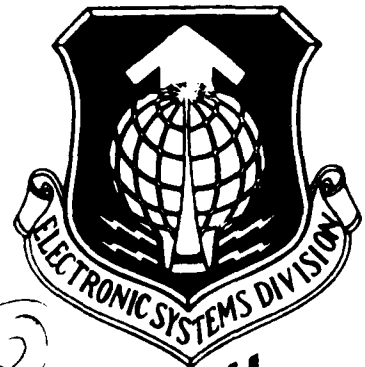
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DEPUTY FOR TECHNICAL OPERATIONS
ELECTRONIC SYSTEMS DIVISION
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REVIEW AND APPROVAL

This technical report has been reviewed and is approved for publication.

Neil D. McQuage

NEIL D. McQUAGE, Major, USAF
Project Manager

James W. Neely, Jr.

JAMES W. NEELY, Jr., Lt Col, USAF
Acting Chief, Technology Applications
Division
Deputy for Technical Operations

FOR THE COMMANDER

C. J. Grewe, Jr.

CHARLES J. GREWE, Jr., Lt Col, USAF
Acting Director, Computer Systems
Engineering
Deputy for Technical Operations

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In this volume, information about selected ESD C3 Embedded Computer Systems (ECS) is presented to illustrate the types of data that could be considered in the development of computer system analogies for sizing and timing studies. Also included are a number of graphic representations of computer system sizing and timing relationships that are based on algorithms developed by various computer scientists during the past several years. Although the relationships are presented in absolute values, users are cautioned not to consider any relationship by itself. Rather, they should be considered additional possible data points in the overall evaluation of a computer system's sizing and timing parameters. Also included are two examples of the application of the procedures discussed in Volume I; a proposed revision of the Data Item Description (DID) entitled, Computer Program Timing and Sizing Data (DI-S-30568), and a list of suggestions for future work to update and improve the estimating procedures.

In addition, a reference listing, an annotated bibliography, and an index are provided. ←

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PREFACE

This volume contains the addendum of the handbook on procedures for estimating computer system sizing and timing parameters during the acquisition life-cycle of Embedded Computer Systems (ECS). The handbook, of which this volume is a part, was developed for use by the engineers and computer scientists of the Electronic Systems Division's Computer Systems Engineering Directorate (ESD/TOI).

The addendum contains supplemental information pertaining to selected ESD C3 Embedded Computer Systems (ECS) that is presented to illustrate the types of data that could be considered in the development of computer system analogies for sizing and timing studies. Also included are a number of graphic representations of computer system sizing and timing relationships that are based on algorithms developed by various computer scientists during the past several years. Although the relationships are presented in absolute values, users are cautioned not to consider any relationship by itself. Rather, they should only be considered additional possible data points in the overall evaluation of a computer system's sizing and timing parameters. Also included are two examples of the application of the procedures discussed in Volume I, a proposed revision of the Data Item Description (DID) entitled, Computer Program Timing and Sizing Data (DI-S-30568), and a list of suggestions for future work to update and improve the estimating procedures.

The handbook consists of two volumes, the first volume discusses procedures and techniques, and this second volume provides an addendum of supplemental information. The primary features and tools are as follows:

Volume I

Procedures
Techniques
Factors and Checklists
Glossary

Volume II

Case Studies
Hardware Specifications
Graphs
Data Item Description

Volume I

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1. INTRODUCTION

1.1 Background.

For each new generation of Command, Control, and Communications (C3) systems, Embedded Computer Systems (ECS) become increasingly critical. There are many reasons for this; computer systems, including software, are performing more functions more rapidly, and they must be reliable under more extreme physical and operational constraints. As more stringent requirements have been imposed upon Command, Control and Communications (C3) system performance (e.g., more targets and target types, more sophisticated signal processing, improved countermeasures and counter-countermeasures, faster responses, and greater reliability), increasing demands have been placed upon the C³ computer systems.

In many system acquisitions, the uncertainties of qualifying and quantifying the hardware and software needs of an ECS have been extensive, with software uncertainties far exceeding those of the hardware. This situation is projected to increase in frequency and severity in the future. The requirement to perform most necessary functions in real-time is very demanding and has thus provided the impetus for continued improvement in hardware and software technologies. However, in spite of these technological improvements, increased operational requirements continue to dictate larger and more sophisticated computer systems and software packages. As a consequence, there is an increasing, if not urgent, need to develop and evaluate embedded computer systems sizing and timing estimates.

The field of computer system acquisition management and engineering is just developing, especially in its ability to derive sizing and timing estimates for entire computer systems and software in the overall computer system environment. Sizing and timing of whole or large segments of computer systems are particularly complex and, at the present state-of-the-art, only appear feasible using models, simulations, benchmarks or monitors. The primary difficulty is the definition of a workload that a

computer system or subsystem must perform. Additionally, the following difficulties in sizing and timing computer systems have been acknowledged:

- lack of standard engineering and management procedures and techniques,
- lack of standard metrics used in developing estimates,
- lack of understanding the relationships between hardware and software characteristics and operational requirements,
- lack of accurate or timely projections of hardware and software resource requirements, and
- lack of awareness of viable system design and technological advances.

The Department of Defense, recognizing these deficiencies, established the DoD Management Steering Committee for embedded computer resources. As stated in the background section of the charter in DoD Directive 5000.29 for the group:

...Current annual expenditures by the Department of Defense on the design, development, acquisition, management and operation support of computer resources embedded within and integral to weapons, communications, command and control, and intelligence systems are measured in the billions of dollars. At the same time, such computer resources have often presented critical cost and schedule problems during the development and acquisition of new defense systems. Even after system implementation and fielding, the software has often proven unreliable...

Computer system resource estimating has historically been characterized by two shortcomings; it has been poorly done and seldom validated. The reasons for poor estimating are numerous. The lack of necessary information resources to implement reliable estimating methodologies is among the most important, also:

- There is no common data base from which to develop computer resource estimates.

- Even where some historical computer systems data exist, there is often no clear understanding of what the data actually represent.

The problems associated with embedded computer system sizing and timing estimates are more pronounced and diverse than those associated with stand-alone systems. When a C³ system is developed with integrated embedded computers, there is often concurrent hardware/software development. An immediate problem, therefore, is that there may be no functioning hardware on which to begin software integration. The concepts of early defect removal using modern programming practices may be less than adequate to prevent severe software or hardware problems when the system is completed. Estimates can be done by use of models, simulations, benchmarks or monitoring; however, these techniques may not be feasible due to costs, time constraints, or lack of relevant data.

The above discussion of the background highlights some of the major problems and concerns regarding estimation of computer system sizing and timing parameters. It also demonstrates the critical need for Air Force managers to acquire standardized engineering and management procedures, now presented in this handbook, to insure that the operational requirements of C³ ECS are met during the system acquisition life-cycle in the most efficient and effective manner.

1.2 Goal and Content.

The main emphasis of this handbook is to provide standard procedures rather than metrics for estimating sizing and timing parameters of ECS in Air Force C³ systems, for use by the engineers and computer scientists of the Electronic Systems Division's Computer Systems Engineering Directorate (ESD/TOI). Such use should enable the engineers and computer scientists of ESD/TOI to better assist other personnel at ESD in conducting sizing and timing studies. IN THE EVENT ESD PERSONNEL NEED ASSISTANCE IN CONDUCTING A SIZING AND TIMING STUDY - CONTACT ESD/TOI.

This handbook consists of two volumes; the first volume contains the procedures and techniques, and this second volume provides an addendum of supplemental information. In the first volume, the procedures structure the function of estimating ECS sizing and timing into three types: initial studies, study updates, and developmental monitoring, and provide a step-by-step program employing many of the techniques used in Validation and Verification (V&V) of systems. The procedural steps are discussed with emphasis on actions that should be taken, risks that should be considered, constraints that may be encountered, and factors that affect the quality of an estimate at various stages of the acquisition. Techniques that can be used in estimating sizing and timing parameters at various stages of the acquisition are discussed. The technique discussions include general information regarding required data, assumptions, application, and level of confidence. In this second volume, information about selected ESD C³ ECS is presented to illustrate the types of data that could be considered in the development of computer system analogies for sizing and timing studies. Also included are a number of graphically illustrated computer system sizing and timing relative relationships that are based on algorithms developed by various computer scientists. In addition, there are two examples that discuss the application of the procedures.

1.3 Organization of this Volume.

The organization of the remainder of this volume is as follows: Tab A provides illustrative information about selected ESD C³ ECS; Tab B presents graphic representations of computer system relationships; Tab C contains two examples of the application of procedures; Tab D presents a proposed revision of DID (DI-S-30568); Tab E contains a list of suggestions for future work to update and improve the estimating procedures; and in addition, there is a reference listing, an annotated bibliography, and an index for use with this handbook.

TAB A COMPUTER SYSTEMS

This tab is provided for illustrative purposes only, and contains two sections of information relative to ESD C³ Embedded Computer Systems (ECS). Information of this type could be useful in the application of analogy techniques. The first section provides a sample listing of ESD C³ major projects. The second section presents a sample listing of generalized computer equipment specifications for some ESD systems.

The Sample ESD C³ Major Projects, Section 1, lists ESD C³ projects alphabetically, gives a brief description of the project's objectives, and lists the major hardware components of each system.

The Sample Generalized Computer Equipment Specifications for Some ESD Systems, Section 2, presents descriptions and specifications relevant to systems cited in Section 1 and are in alphabetical order by manufacturer.

The following is an index to Tab A, Sections 1 and 2.

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TAB A

SECTION 1 SAMPLE ESD C3 MAJOR PROJECTS

The following information on ESD projects is illustrative only. The projects are dynamic and subject to change.

SECTION 1 SAMPLE ESD C3 MAJOR PROJECTS

Air Force Satellite Communications System 1205. Acquisition of UHF airborne/ground force terminals, airborne/ground command post terminals, ancillary equipment for operational control and communications transponders on selected Air Force satellites. The associated family of modular UHF transceivers will provide a command communications capability in the line-of-sight mode. The full-grown family of modular UHF radios will result in a common base to provide the transceiver for the satellite SIOP and Force communications terminals.

This system consists of:

- 2 ROLM 1603 minicomputers in a multiprocessor mode.
- 1 each, magnetic tape cartridge extended memory, processor control unit, and status display unit.

Air Force World Wide Military Command and Control System (AFWMCCS). Involves systems planning and engineering for Air Force elements of the World Wide Military Command and Control System. Activities will focus on intersystem engineering of selected AFWMCCS existing and planned assets.

This system consists of:

- Honeywell H-6050 computer systems.
- Honeywell H-6060 computer systems.
- Honeywell H-6080 computer systems.
- Honeywell H-716 minicomputers for communications and I/O controllers.

COBRA DANE 633A. Installation of a phased array radar on Shemya AFS, Aleutian Islands, to collect intelligence data of Soviet missile development tests. Corollary missions are early warning and satellite tracking.

This system consists of:

- 1 Control Data Corporation (CDC) Cyber 74-18 with 5 CDC 243-2 display consoles.
- 1 Raytheon RDS-500 minicomputer.
- 1 Digital Equipment Corporation PDP-11, receives post mission processing output at FTD and prepares tape for U-1108.
- 1 UNIVAC U-1108 at FTD.
- 1 Intel 8080, acts as a communications controller.
- 1 CDC Cyber 74-14.

COMBAT GRANDE. Insure maintenance of Spanish Air Force air defense system. Provide additional communication links for the network and improve existing communications, command and control, and weapons control.

This system consists of:

- 2 Hughes Aircraft Corp. H-5118 computers, one used as the main processing and the other as backup.
- 37 Texas Instruments TI-980A minicomputers, 28 as display console controllers, 2 as primary and backup display system controllers, and 7 remotely located at the 7 long range radar sites.
- 4 Digital Equipment Corporation PDP-11/05 minicomputers for call processing and control within the PABX.

Combat Theater Communications 478T. Acquisition of a new hybrid analog/digital and digital communications equipment both for Air Force unique tactical requirements and for the DOD Joint Tactical Communications (TRI-TAC) Program. Within the TRI-TAC Program, the 478T office carries out the development, test, and production of equipment assigned as Air Force responsibility and insures that USAF requirements are met by all of the equipment procured through this joint service program. Also responsible for the interoperability of TRI-TAC equipment with other communications equipment within the tactical Air Force environment.

This system consists of:

- UNIVAC U-1600 (same as AN/UYK-20) central processor with a microprocessor data-base controller and I/O controller, visual display units (VDU's), magnetic tape units, discs, and line printers.

CONUS Over-the-Horizon Backscatter Radar 414L. Provides long-range detection of aircraft approaching North America as part of the NORAD air surveillance and warning capability. Distinguishing technical feature of OTH-B is its ability to detect targets at all altitudes and at extended ranges. The present program is to build and test a prototype.

This system consists of:

- 1 UNIVAC U-1110 computer and peripherals.
- 2 UNIVAC U-1600 minicomputers and peripherals.
- 1 General Electric special purpose signal processor.
- Hazeltine display equipment.

E-3A Airborne Warning and Control System 411L. Provides survivable airborne air surveillance capability and command, control, and communications functions. Its distinguishing technical feature is the capability to detect and track aircraft operating at high and low altitudes over both land and water. Used by the Tactical Air Command with Tinker AFB as the main operating base, aircraft may deploy throughout the

United States and overseas to provide surveillance, warning and control in a variety of peacetime and wartime situations.

In each aircraft is/are:

- 1 IBM 4 Pi CC-1 computer for applications program.
- 1 Northrop NOC 1070 minicomputer for navigation.
- 2 Delco Magic 311 minicomputers for navigation.
- 1 Westinghouse radar data correlator.
- 1 IBM 4 Pi AP-1A for TDMA communication terminal control.

Ground support consists of:

- 1 IBM 370/155.
- 1 Redifon 200A for flight simulator.

E-4 Airborne Command Post 481B. Provides the National Military Command System (NMCS) and Strategic Air Command (SAC) with an airborne command and control system that will operate during the pre-, trans-, and post-attack phases of a general war. As a survivable emergency extension of NMCS and SAC ground command control centers, provides high confidence in our ability to execute and control SIOP forces during nuclear war.

In each aircraft is/are:

- A Burroughs D-machine used as communications processor.
- 2 EECO paper type readers.
- 2 Potter magnetic tape units.
- 2 Data Magic line printers.

Ground support consists of:

- 1 each, Burroughs keyboard/printer, disc, card reader, keyboard/CRT terminal, and EECO paper tape reader & punch.

Joint Surveillance System (JSS) 968H. The JSS program has been established to acquire and deploy a peacetime air surveillance and control system to replace the Semi-Automatic Ground Environment (SAGE) system for the U.S. and Canada. For Canada, the mission is expanded to include support of wartime air defense functions and in Alaska the mission includes the performance of tactical air control functions.

This system consists of:

- 1 large computer complex and 20 to 30 display consoles at each RDCC.

Joint Tactical Information Distribution System 634B. A program to develop a high capacity, reliable, jam-protected, secure, digital information distribution system which will provide an unprecedented degree of interoperability between data collection elements, combat elements, and command and control centers within a military theater of operations.

This system consists of:

- 3 ASIT's, one for each Tactical Data Information Link, TADIL-A, TADIL-B, TADIL-C.
- Translator Processor (TP) might be an AN/UYK-20 (same as Air Force U-1600 by UNIVAC) or equivalent.

NORAD Cheyenne Mountain Complex Improvements 427M. Acquisition of data processing equipment, software, displays, and communications for the NORAD Cheyenne Mountain Complex. The Core Processing Segment, Modular Display Segment, and the Communications System Segment will provide NORAD with an integrated, responsive capability and a growth potential over a projected 10-year life span without major changes to equipment or software.

This system consists of:

- 2 Honeywell H-6050 computers.
- 6 Data General NOVA 840 minicomputers.
- 3 Honeywell H-6080 computers.
- 2 Honeywell H-716 minicomputers.
- 3 Honeywell Datnet 355 processors.
- 3 SSF alphanumeric consoles.
- 4 Data General NOVA 840 interface processors.
- 1 Data General DAPT graphics processor.
- 40 Data General NOVA 1220 NCMC display controllers and displays.
- 11 non-interactive displays.

PAVE PAWS 2059. Two dual-faced phased array radars, one to be deployed on the East Coast and one of the West Coast. This system will be operated by the Aerospace Defense Command and will provide warning to the National Command Authority of a sea-launched ballistic missile attack against the Continental United States.

This system consists of:

- 2 Control Data Corporation (CDC) Cyber 174-12 computers.
- 3 CDC System 17 display processors.
- 6 CDC 777 displays, 6 tape drives, 4 disc units.

SAC Digital Information Network (SACDIN) 1136. A program for an integrated SAC command-wide digital record communications system to meet, with updating, the requirements for command-control and support data transmission into the 1990s.

This system consists of:

- 5 Subnet Communication Processors (SCP)
- 32 Base Communications Processors (BCP)
- 26 Missile Base Communications Processors (MBCP)
- 150 User Terminal Elements (UTE).

Tactical Air Control System Improvements (TACSI) 485L. This program will give the Tactical Air Control System (TACS) increased operational capabilities needed for combat command and control of tactical aerospace operations. Improvements consist of mobile communications and electronic systems capable of modular world-wide deployment that are compatible with the TACS and interoperable with Army, Navy, and Marine Corps tactical data systems.

This system consists of:

- UNIVAC AN/UYK-7 computers for data processing and display
- Control Data Corporation (CDC) AN/UYK-25 computers for communications processors.
- CDC UYK-25 for data source terminals.

TAB A
SECTION 2

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS
FOR SOME ESD SYSTEMS

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

The following information is generalized data based on manufacturer's specifications. This equipment is used in the ESD system(s) cited in the comments, though configuration may actually vary.

MANUFACTURER & MODEL

Control Data Corporation Cyber 74

DATA FORMAT

Word length (bits)	60 in CPU & main storage, 12 in peripheral processors's & I/O's
Fixed point operand (bits)	60 or 18 in CPU; 6, 12, or 18 in peripherals
Instruction length (bits)	15 or 30 in CPU, 12 or 24 in peripherals
Floating point	Yes

MAIN STORAGE

Type	Magnetic core
Cycle time (microseconds)	1.0 per word
Capacity (words)	32K to 131K (Dual processors start at 65K)
Increments (words)	4K banks
Interleaving	Maximum data rate 10M words per second
Buffer (cache) storage	
Extended memory	Magnetic core, up to 2M words in 125K blocks, 3.2 microseconds per 8 word record

CENTRAL PROCESSOR

CPU configuration	Can dual with a Cyber 73 unified CPU
Registers	8-60 bit operand (instruction stack), 8-18 bit address, 8-18 bit index; 64 index registers in peripherals
No. directly addressable words	
Indirect addressing	Not in CPU, one level in peripherals
Machine cycle time	
Instruction time (microseconds)	.3 fixed add, .4 float add, 1.0 multiply, 2.9 divide: typical MIPS: 3 for single, 3.7 for dual;
Hardware functional units	10 independent, concurrent units: 2 increment, 2 multiply, 1 each: add, long add, shift, divide, Boolean algebra, and branch
Real-time clock or timer	

INPUT/OUTPUT CONTROL

I/O word size (bits)	12
Maximum I/O rate (words/second)	1M
No. external interrupt levels	
Number I/O channels	12 or 24 (all computer to computer capable)

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

CDC Cyber 74 (continued)

<u>PERIPHERAL EQUIPMENT</u>	
Disc pack storage	Up to 8 handlers per controller, up to 118M 6 bit characters per handler
Non-interchangeable disc storage	Yes
Drum storage	No
Magnetic tape	7 or 9 Track, 8 models, 37.5 to 150 inches per second, 200 to 1600 bits per inch
Punched card	Up to 1200 cards per minute read
Paper tape	
Printer speed	Up to 1200 lines per minute
Terminals	Synchronous or Asynchronous
Other	

COMMENTS: Two systems used in Cobra Dane have 5 display consoles.

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

The following information is generalized data based on manufacturer's specifications. This equipment is used in the ESD system(s) cited in the comments, though configuration may actually vary.

MANUFACTURER & MODEL

Control Data Corporation Cyber 174-12

<u>DATA FORMAT</u>	
Word length (bits)	60 in CPU and main storage, 12 in peripheral processor's and I/O's
Fixed point operand (bits)	60 or 18 in CPU; 6, 12, or 18 in peripherals
Instruction length (bits)	15 or 30 in CPU, 12 or 24 in peripherals
Floating point	Yes
<u>MAIN STORAGE</u>	
Type	Metal Oxide Semiconductor
Cycle time (microseconds)	0.4 per word
Capacity (words)	65K to 262K
Increments (words)	32K banks
Interleaving	8 banks gives a 0.05 microsecond effective cycle time
Buffer (cache) storage	No
Extended memory	Magnetic core, up to 2M words in 125K word banks, 3.2 microseconds per 8 word record fetch
<u>CENTRAL PROCESSOR</u>	
CPU configuration	The 174 CPU is actually 2 CDC Cyber 173 CPU's
Registers	8 60 bit operand, 8 18 bit address, 8 18 bit index
No. directly addressable words	
Indirect addressing	Not used in CPU, one level in peripherals
Machine cycle time	
Instruction time (microseconds)	Fixed point add 0.25
Hardware functional units	Unified arithmetic unit performs all instructions
<u>Real-time clock or timer</u>	
<u>INPUT/OUTPUT CONTROL</u>	
I/O word size (bits)	12
Maximum I/O rate (words/second)	4M 6 bit characters per second
No. external interrupt levels	
Number I/O channels	12 or 24
<u>PERIPHERAL EQUIPMENT</u>	
Disc pack storage	Up to 8 handlers per controller, up to 237M characters per handler
Non-interchangeable disc storage	No
Drum storage	

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

CDC Cyber 174-12 (continued)

PERIPHERAL EQUIPMENT (continued)	
Magnetic tape	7 or 9 track, 8 models, up to 200 inches per second, up to 1600 bits per inch
Punched card	Reads up to 1200 cards per minute, punches up to 250 cpm
Paper tape	
Printer speed	Up to 2000 lines per minute
Terminals	Synchronous /asynchronous
Other	Communications processor

COMMENTS: Has a two word overlap or lookahead in the instruction stack. Two systems used in PAVE PAWS with 3 display peripheral processors, 6 CDC 777 displays, 6 tape drives, and 4 disc units.

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

The following information is generalized data based on manufacturer's specifications. This equipment is used in the ESD system(s) cited in the comments, though configuration may actually vary.

MANUFACTURER & MODEL

Control Data Corporation System 17

<u>DATA FORMAT</u>	
Word length (bits)	16 + 2 (Parity)
Fixed point operand (bits)	16
Instruction length (bits)	16 or 32
Floating point	
<u>MAIN STORAGE</u>	
Type	Metal Oxide Semiconductor
Cycle time (microseconds)	0.6 or 0.9
Capacity (words)	4K to 16K words
Increments (words)	
Interleaving	
Buffer (cache) storage	
Extended memory	
<u>CENTRAL PROCESSOR</u>	
CPU configuration	
Registers	2 accumulators; 2 index
No. directly addressable words	256
Indirect addressing	Multi-level
Machine cycle time	
Instruction time (microseconds)	Full word add time 1.2 or 1.8
Hardware functional units	Standard multiply and divide; optional byte manipulation
Real-time clock or timer	Optional
<u>INPUT/OUTPUT CONTROL</u>	
I/O word size (bits)	16
Maximum I/O rate (words/second)	1.6M
No. external interrupt levels	2 to 16
Number I/O channels	
<u>PERIPHERAL EQUIPMENT</u>	
Disc pack storage	Yes
Non-interchangeable disc storage	Yes
Drum storage	Yes
Magnetic tape	Up to 60K characters per second
Punched card	Up to 1600 cards per minute input and 460 out
Paper tape	Up to 400 characters per second in and 150 out
Printer speed	
Terminals	CRT
Other	Optical Character Reader, analog to digital converters

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

CDC System 17 (continued)

COMMENTS: Three units used as display processors in PAVE PAWS.

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

The following information is generalized data based on manufacturer's specifications. This equipment is used in the ESD system(s) cited in the comments, though configuration may actually vary.

MANUFACTURER & MODEL

Control Data Corporation AN/UYK-25 MP60

<u>DATA FORMAT</u>	
Word length (bits)	32
Fixed point operand (bits)	32
Instruction length (bits)	32
Floating point	standard
<u>MAIN STORAGE</u>	
Type	Magnetic core, 36 bits (with error correction code)
Cycle time (microseconds)	1
Capacity (words)	32K - 500K
Increments (words)	32K, 65K
Interleaving	No
Buffer (cache) storage	Microstore - 4K; 0.17 microsecond cycle RAM
Extended memory	No
<u>CENTRAL PROCESSOR</u>	
CPU configuration	Single processor or up to 8 CPU's in an array
Registers	256 general purpose
No. directly addressable words	512K
Indirect addressing	Yes
Machine cycle time	
Instruction time (microseconds)	Fixed point add 2.2
Hardware functional units	Standard: float point, fix point add and subtract, multiply and divide, byte/bit manipulation, literal instructions
Real-time clock or timer	Optional
<u>INPUT/OUTPUT CONTROL</u>	
I/O word size (bits)	16
Maximum I/O rate (words/second)	62.5K
No. external interrupt levels	128
Number I/O channels	16 per I/O controller, up to 4 I/O controller's
<u>PERIPHERAL EQUIPMENT</u>	
Disc pack storage	872M bit per handler, 8 handlers per controller
Non-interchangeable disc storage	1000M bit per handler, up to 6 handlers
Drum storage	No
Magnetic tape	7 or 9, up to 1600 bits per inch, up to 200 inches per second

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

CDC AN/UYK-25 (continued)

PERIPHERAL EQUIPMENT (continued)	
Punched card	1500 cards per minute in; 250 cards per minute out
Paper tape	600 characters per second in; 100 characters per second out
Printer speed	2000 lines per minute
Terminals	TTY, asynchronous CRT
Other	OCR, analog to digital converter, graphics, communications

COMMENTS: Two systems used in TACSI: one as a communications processor and the other as a data source terminal controller.

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

The following information is generalized data based on manufacturer's specifications. This equipment is used in the ESD system(s) cited in the comments, though configuration may actually vary.

MANUFACTURER & MODEL

Data General NOVA 840

<u>DATA FORMAT</u>	
Word length (bits)	16
Fixed point operand (bits)	16
Instruction length (bits)	16
Floating point	Optional
<u>MAIN STORAGE</u>	
Type	Magnetic core
Cycle time (microseconds)	0.8
Capacity (words)	16K to 131K
Increments (words)	
Interleaving	
Buffer (cache) storage	
Extended memory	
<u>CENTRAL PROCESSOR</u>	
CPU configuration	Single processor
Registers	4 accumulator, 2 index
No. directly addressable words	1,024
Indirect addressing	Multi-level
Machine cycle time	
Instruction time (microseconds)	Full word add time 0.8
Hardware functional units	Standard: byte manipulation; optional: multiply and divide, floating point
Real-time clock or timer	Optional
<u>INPUT/OUTPUT CONTROL</u>	
I/O word size (bits)	16
Maximum I/O rate (words/second)	1.25M
No. external interrupt levels	16
Number I/O channels	
<u>PERIPHERAL EQUIPMENT</u>	
Disc pack storage	Yes
Non-interchangeable disc storage	Yes
Drum storage	No
Magnetic tape	60K characters per second maximum
Punched card	Reads up to 1000 cards per minute
Paper tape	Reads up to 400 characters per second, punches 63.3
Printer speed	
Terminals	CRT, TTY
Other	Plotter, communications, analog to digital converters

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

Data General NOVA 840 (continued)

COMMENTS: Six are used in NORAD Cheyenne Mountain Complex Improvements in the central system and four are used as interface processors.

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

The following information is generalized data based on manufacturer's specifications. This equipment is used in the ESD system(s) cited in the comments, though configuration may actually vary.

MANUFACTURER & MODEL

Data General NOVA 1220

DATA FORMAT

Word length (bits) 16
Fixed point operand (bits) 16
Instruction length (bits) 16

Floating point

MAIN STORAGE

Type Magnetic core
Cycle time (microseconds) 1.2
Capacity (words) 4K to 32K
Increments (words)
Interleaving
Buffer (cache) storage
Extended memory

CENTRAL PROCESSOR

CPU configuration

Registers 4 accumulators; 2 index
No. directly addressable words 1,024
Indirect addressing Multi-level
Machine cycle time
Instruction time (microseconds) Full word add 1.35
Hardware functional units Standard: byte manipulation; optional: multiply and divide, floating point
Optional

Real-time clock or timer

INPUT/OUTPUT CONTROL

I/O word size (bits) 16
Maximum I/O rate (words/second) 833K
No. external interrupt levels 16
Number I/O channels

PERIPHERAL EQUIPMENT

Disc pack storage Yes
Non-interchangeable disc storage Yes
Drum storage No
Magnetic tape 60K characters per second
Punched card Up to 1000 cards per minute input
Paper tape 400 characters per second in and 63.3 out
Printer speed
Terminals CRT
Other Plotters, analog to digital converters, communications

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

Data General NOVA 1220 (continued)

COMMENTS: Forty are used in NORAD Cheyenne Mountain Complex Improvements
as display processors and controllers.

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

The following information is generalized data based on manufacturer's specifications. This equipment is used in the ESD system(s) cited in the comments, though configuration may actually vary.

MANUFACTURER & MODEL

Digital Equipment Corporation PDP 11/05

<u>DATA FORMAT</u>	
Word length (bits)	16
Fixed point operand (bits)	16
Instruction length (bits)	16 or 32 or 48
Floating point	
<u>MAIN STORAGE</u>	
Type	Magnetic core
Cycle time (microseconds)	0.9 per word
Capacity (words)	4K to 28K
Increments (words)	
Interleaving	
Buffer (cache) storage	
Extended memory	
<u>CENTRAL PROCESSOR</u>	
CPU configuration	Single processor
Registers	8 accumulators, 8 index
No. directly addressable words	32K (28K in memory, 4K in I/O semi-conductor memories)
Indirect addressing	One level
Machine cycle time	
Instruction time (microseconds)	Full word add 3.7
Hardware functional units	Optional: multiply, divide; standard: byte manipulation, literal instructions
Real-time clock or timer	Standard
<u>INPUT/OUTPUT CONTROL</u>	
I/O word size (bits)	16
Maximum I/O rate (words/second)	2M
No. external interrupt levels	Variable
Number I/O channels	
<u>PERIPHERAL EQUIPMENT</u>	
Disc pack storage	Yes
Non-interchangeable disc storage	Yes
Drum storage	Special order
Magnetic tape	36K maximum characters per second
Punched card	300 maximum cards per minute in, 75 out
Paper tape	300 maximum characters per second in, 50 out
Printer speed	
Terminals	CRT
Other	Communications interface

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

DEC PDP 11/05 (continued)

COMMENTS: Used in COMBAT GRANDE system for call processing and control within the PABX.

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

The following information is generalized data based on manufacturer's specifications. This equipment is used in the ESD system(s) cited in the comments, though configuration may actually vary.

MANUFACTURER & MODEL

Digital Equipment Corporation PDP 11/10
and 11/40

DATA FORMAT

Word length (bits)	16
Fixed point operand (bits)	16
Instruction length (bits)	16 or 32 or 48; depends on addressing and extensions

Floating point

MAIN STORAGE

Type	Magnetic core
Cycle time (microseconds)	900 microseconds with interleaving
Capacity (words)	28K words (124K words for 11/40)
Increments (words)	
Interleaving	Optional
Buffer (cache) storage	
Extended memory	

CENTRAL PROCESSOR

CPU configuration	Single processor
Registers	8 general purpose; 2 of which are program counter and hardware stack
No. directly addressable words	64K bytes
Indirect addressing	
Machine cycle time	
Instruction time (microseconds)	4.6 add from memory, 7 memory move (2.38 add, 3.2 move for 11/40)
Hardware functional units	
Real-time clock or timer	

INPUT/OUTPUT CONTROL

I/O word size (bits)	16
Maximum I/O rate (words/second)	2.5M
No. external interrupt levels	Multilevel priority interrupt system
Number I/O channels	

PERIPHERAL EQUIPMENT

Disc pack storage	Yes
Non-interchangeable disc storage	Fixed head
Drum storage	No
Magnetic tape	7 or 9 track, or cassette
Punched card	Yes
Paper tape	Yes
Printer	Yes
Terminals	CRT, vector graphics, storage tube
Other	analog to digital converter

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

DEC PDP 11/10 and 11/40 (continued)

COMMENTS: Used in COBRA DANE to receive post mission processing output
at FTD and prepare tape for input to UNIVAC U-1180

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

The following information is generalized data based on manufacturer's specifications. This equipment is used in the ESD system(s) cited in the comments, though configuration may actually vary.

MANUFACTURER & MODEL

Honeywell H-716

<u>DATA FORMAT</u>	
Word length (bits)	16
Fixed point operand (bits)	16
Instruction length (bits)	16
Floating point	
<u>MAIN STORAGE</u>	
Type	Magnetic core
Cycle time (microseconds)	0.755 per word
Capacity (words)	8K to 65K
Increments (words)	
Interleaving	
Buffer (cache) storage	
Extended memory	
<u>CENTRAL PROCESSOR</u>	
CPU configuration	Single processor
Registers	1 accumulator, 2 index
No. directly addressable words	1,024
Indirect addressing	Multi-level
Machine cycle time	
Instruction time (microseconds)	Full word add 1.55
Hardware functional units	Standard multiply and divide and byte manipulation
Real-time clock or timer	Standard
<u>INPUT/OUTPUT CONTROL</u>	
I/O word size (bits)	16
Maximum I/O rate (words/second)	1M
No. external interrupt levels	63
Number I/O channels	
<u>PERIPHERAL EQUIPMENT</u>	
Disc pack storage	Yes
Non-interchangeable disc storage	Yes
Drum storage	No
Magnetic tape	112K characters per second maximum
Punched card	Up to 1050 cards per minute in, 100 out
Paper tape	Up to 300 characters/second in, 110 out
Printer	Up to 6 printers
Terminals	Synchronous and asynchronous
Other	Cassette tape, graphics, analog to digital and communication interfaces

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

Honeywell H-716 (continued)

COMMENTS: Two Honeywell H-716's are used in the NORAD Cheyenne Mountain Complex Improvements as communication processors with 3 Honeywell Datanet 355 processors. Also used in WWMCCS systems as a communications controller or front end device.

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

The following information is generalized data based on manufacturer's specifications. This equipment is used in the ESD system(s) cited in the comments, though configuration may actually vary.

MANUFACTURER & MODEL

Honeywell H-6050 and H-6060

DATA FORMAT

Word length (bits)	36 (plus parity)
Fixed point operand (bits)	18 or 36 or 72
Instruction length (bits)	36
Floating point	Single or double word

MAIN STORAGE

Type	Magnetic core
Cycle time (microseconds)	1.2 (2 word fetch)
Capacity (words)	98K to 524K
Increments (words)	Varies
Interleaving	2 way
Buffer (cache) storage	
Extended memory	Bulk storage system, 1 to 3.5M 9 bit bytes, 6M bytes per second transfer rate

CENTRAL PROCESSOR

CPU configuration	1 to 4 multiprocessor
Registers	1 72 bit AQ accumulator, 8 18 bit index, 1 18 bit base address, 1 18 bit instruction counter, 1 27 bit timer, 1 8 bit exponent
No. directly addressable words	
Indirect addressing	Any level with indexing at each level
Machine cycle time	
Instruction time (microseconds)	Fixed point add time 1.51; typical MIPS .5 to .9 for single or dual processor
Hardware functional units	
Real-time clock or timer	Standard

INPUT/OUTPUT CONTROL

I/O word size (bits)	36
Maximum I/O rate (words/second)	1M
No. external interrupt levels	
Number I/O channels	

PERIPHERAL EQUIPMENT

Disc pack storage	Up to 16 drives per controller, each drive up to 133M characters
Non-interchangeable disc storage	
Drum storage	
Magnetic tape	Up to 16 drives per controller, up to 160K characters per second per drive (only 2 can operate at the same time)

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

Honeywell H-6050 and H-6060 (continued)

PERIPHERAL EQUIPMENT (continued)	
Punched card	Up to 1050 cards per minute in, 400 out
Paper tape	500 characters per second read, 150 punch
Printer speed	Up to 1200 lines per minute
Terminals	Synchronous or asynchronous
Other	Magnetic character reader, optical character reader, plotters

COMMENTS: The H-6060 is the same as the H-6050 except that it offers an Extended Instruction Set of over 100 new instructions that can cut time and memory requirements in data processing, decimal arithmetic, etc. The H-6050 was the original WWMCCS computer, but has been replaced by H-6060's, mostly in a 2 CPU multi-processor configuration. The NORAD Cheyenne Mountain Complex Improvements has H-6050 systems.

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

The following information is generalized data based on manufacturer's specifications. This equipment is used in the ESD system(s) cited in the comments, though configuration may actually vary.

MANUFACTURER & MODEL	Honeywell H-6080
<u>DATA FORMAT</u>	
Word length (bits)	36 (plus parity)
Fixed point operand (bits)	18 or 36 or 72
Instruction length (bits)	36
Floating point	Single or double word
<u>MAIN STORAGE</u>	
Type	Magnetic core
Cycle time (microseconds)	0.5 (2 word fetch)
Capacity (words)	131K to 1M
Increments (words)	Varies
Interleaving	2 or 4 way
Buffer (cache) storage	
Extended memory	Bulk store system; 1 to 3.5M 9 bit bytes, 10M bytes per second transfer rate
<u>CENTRAL PROCESSOR</u>	
CPU configuration	1 to 4 multiprocessor
Registers	1 72 bit AQ accumulator, 8 18 bit index, 1 18 bit base address, 1 18 bit instruction counter, 1 27 bit timer, 1 18 bit exponent
No. directly addressable words	
Indirect addressing	Any level with indexing at each level
Machine cycle time	
Instruction time (microseconds)	Fixed point add time 0.71; typical MIPS 1 to 1.8 for single or dual processor
Hardware functional units	
Real-time clock or timer	Standard
<u>INPUT/OUTPUT CONTROL</u>	
I/O word size (bits)	36
Maximum I/O rate (words/second)	1M
No. external interrupt levels	
Number I/O channels	
<u>PERIPHERAL EQUIPMENT</u>	
Disc pack storage	Up to 16 drives per controller, each drive up to 133M characters
Non-interchangeable disc storage	
Drum storage	
Magnetic tape	Up to 16 drives per controller, up to 160K characters per second per drive, (only 2 can operate at the same time)

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

Honeywell H-6080 (continued)

PERIPHERAL EQUIPMENT (continued)	
Punched card	Up to 1050 cards per minute in, 400 out
Paper tape	500 characters per second read, 150 punch
Printer speed	Up to 1200 lines per minute
Terminals	Synchronous or asynchronous
Other	Magnetic or optical character readers, plotters

COMMENTS: The H-6080 is usually in dual configuration and is being introduced into the WWMCCS system. Three H-6080's are in the NORAD Cheyenne Mountain Complex Improvements system.

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

The following information is generalized data based on manufacturer's specifications. This equipment is used in the ESD system(s) cited in the comments, though configuration may actually vary.

MANUFACTURER & MODEL

IBM 370/155

DATA FORMAT

Word length (bits)	32 (4-8 bit bytes)
Fixed point operand (bits)	16 or 32 in binary mode
Instruction length (bits)	2 or 4 or 6 bytes
Floating point	Standard 1 or 2 word

MAIN STORAGE

Type	Magnetic core, virtual
Cycle time (microseconds)	2.07 read or write for 4 word blocks
Capacity (words)	66K to 500K
Increments (words)	33K to 131K
Interleaving	No
Buffer (cache) storage	115 microseconds for 2 bytes; 8K bytes capacity

Extended memory

CENTRAL PROCESSOR

CPU configuration	Single processor
Registers	16 or 32 bit for index, accumulator, or base address
No. directly addressable words	No
Indirect addressing	115 microseconds
Machine cycle time	Add time: 0.99 microseconds (32 bit binary field), 4.93 microseconds (5 digit decimal field)
Instruction time (microseconds)	
Hardware functional units	
Real-time clock or timer	Standard

INPUT/OUTPUT CONTROL

I/O word size (bits)	
Maximum I/O rate (words/second)	5.4M bytes per second
No. external interrupt levels	
Number I/O channels	2 to 5 block multiplex, 1 or 2 byte multiplex

PERIPHERAL EQUIPMENT

Disc pack storage	Up to 32 drives, each drive up to 200M bytes
Non-interchangeable disc storage	Each drive stores up to 11.2M bytes
Drum storage	IBM data module (trademark) up to 69.8M bytes
Magnetic tape	9 track, up to 6250 bits per inch, up to 200 inches per second, up to 8 drives per controller

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

IBM 370/150 (continued)

PERIPHERAL EQUIPMENT (continued)	
Punched card	Up to 1000 cards per minute in, 500 out
Paper tape	Reads up to 100 characters per second
Printer speed	Up to 2500 lines per minute
Terminals	CRT, graphic, TTY, sync/async
Other	Optical or magnetic character readers, programmable communication processor

COMMENTS: One system used in AWACS in ground support.

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

The following information is generalized data based on manufacturer's specifications. This equipment is used in the ESD system(s) cited in the comments, though configuration may actually vary.

MANUFACTURER & MODEL

Intel 80

DATA FORMAT

Word length (bits)	8
Fixed point operand (bits)	8 or 16
Instruction length (bits)	8 or 16 or 24
Floating point	

MAIN STORAGE

Type	Semiconductor
Cycle time (microseconds)	2.0 per word
Capacity (words)	4K to 16K
Increments (words)	
Interleaving	
Buffer (cache) storage	
Extended memory	

CENTRAL PROCESSOR

CPU configuration	Single processor
Registers	1 accumulator, 6 index
No. directly addressable words	65K
Indirect addressing	One level
Machine cycle time	
Instruction time (microseconds)	Full word add 2.0
Hardware functional units	Byte manipulation, literal instructions
Real-time clock or timer	No

INPUT/OUTPUT CONTROL

I/O word size (bits)	8
Maximum I/O rate (words/second)	0.5M
No. external interrupt levels	1
Number I/O channels	

PERIPHERAL EQUIPMENT

Disc pack storage	No
Non-interchangeable disc storage	No
Drum storage	No
Magnetic tape	
Punched card	
Paper tape	150 cards per second input
Printer speed	
Terminals	
Other	

COMMENTS: Used in COBRA DANE as communications controller.

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

The following information is generalized data based on manufacturer's specifications. This equipment is used in the ESD system(s) cited in the comments, though configuration may actually vary.

MANUFACTURER & MODEL		Raytheon RDS-500
<u>DATA FORMAT</u>		
Word length (bits)		16
Fixed point operand (bits)		16
Instruction length (bits)		16
Floating point		Yes
<u>MAIN STORAGE</u>		
Type		Magnetic core
Cycle time (microseconds)		0.8 or 0.9 per word
Capacity (words)		8K to 65K
Increments (words)		
Interleaving		
Buffer (cache) storage		
Extended memory		
<u>CENTRAL PROCESSOR</u>		
CPU configuration		Single processor
Registers		8 general purpose accumulators, 8 index
No. directly addressable words		65K
Indirect addressing		No
Machine cycle time		
Instruction time (microseconds)		Full word add 1.6 or 1.8
Hardware functional units		Optional: multiply/divide, float point; standard: byte manipulation, literal instructions
Real-time clock or timer		Optional
<u>INPUT/OUTPUT CONTROL</u>		
I/O word size (bits)		16
Maximum I/O rate (words/second)		2.5M
No. external interrupt levels		16
Number I/O channels		
<u>PERIPHERAL EQUIPMENT</u>		
Disc pack storage		Yes
Non-interchangeable disc storage		Yes
Drum storage		No
Magnetic tape		30K or 60K or 120K characters per second
Punched card		300 or 1000 cards per second in; 100 or 400 out
Paper tape		300 characters per second in, 110 out
Printer speed		Yes
Terminals		Array processors, plotters, CRT's
Other		Communications

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

Raytheon RDS-500 (continued)

COMMENTS: Used in COBRA DANE as a I/O control processor.

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

The following information is generalized data based on manufacturer's specifications. This equipment is used in the ESD system(s) cited in the comments, though configuration may actually vary.

MANUFACTURER & MODEL

ROLM 1603 (Ruggednova)

<u>DATA FORMAT</u>	
Word length (bits)	16
Fixed point operand (bits)	16
Instruction length (bits)	16
Floating point	
<u>MAIN STORAGE</u>	
Type	Magnetic core or semiconductor
Cycle time (microseconds)	1.2 per word
Capacity (words)	Up to 32K
Increments (words)	256
Interleaving	
Buffer (cache) storage	
Extended memory	
<u>CENTRAL PROCESSOR</u>	
CPU configuration	1 or 2 multiprocessor
Registers	4 accumulators, 2 index
No. directly addressable words	1,024
Indirect addressing	Multi-level
Machine cycle time	
Instruction time (microseconds)	Full word add 5.9
Hardware functional units	Optional: multiply, divide; standard: byte manipulation
Real-time clock or timer	Optional
<u>INPUT/OUTPUT CONTROL</u>	
I/O word size (bits)	16 bits
Maximum I/O rate (words/second)	285K
No. external interrupt levels	16 to 256 levels
Number I/O channels	
<u>PERIPHERAL EQUIPMENT</u>	
Disc pack storage	No
Non-interchangeable disc storage	Yes
Drum storage	No
Magnetic tape	60K characters per second maximum
Punched card	400 cards per minute in
Paper tape	300 characters per second in, 63 out
Printer speed	
Terminals	Yes
Other	Data communications interfaces, analog to digital converter

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

ROLM 1603 (Ruggednova) (continued)

COMMENTS: Used in dual processor mode in the Air Force Satellite
Communications System.

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

The following information is generalized data based on manufacturer's specifications. This equipment is used in the ESD system(s) cited in the comments, though configuration may actually vary.

MANUFACTURER & MODEL

Texas Instruments TI-980A

<u>DATA FORMAT</u>	
Word length (bits)	16
Fixed point operand (bits)	16
Instruction length (bits)	16 or 32
Floating point	
<u>MAIN STORAGE</u>	
Type	Semiconductor
Cycle time (microseconds)	0.75 per word
Capacity (words)	4K to 65K
Increments (words)	
Interleaving	
Buffer (cache) storage	
Extended memory	
<u>CENTRAL PROCESSOR</u>	
CPU configuration	
Registers	2 accumulators, 1 index
No. directly addressable words	65K
Indirect addressing	One-level
Machine cycle time	
Instruction time (microseconds)	Full word add 1.75
Hardware functional units	Standard: multiply and divide, byte manipulation, literal instructions
Real-time clock or timer	Optional
<u>INPUT/OUTPUT CONTROL</u>	
I/O word size (bits)	16
Maximum I/O rate (words/second)	1.3M
No. external interrupt levels	2 - 64
Number I/O channels	
<u>PERIPHERAL EQUIPMENT</u>	
Disc pack storage	Yes
Non-interchangeable disc storage	Yes
Drum storage	No
Magnetic tape	300K characters per second maximum speed
Punched card	300 cards per minute in; 100 out
Paper tape	300 characters per second in; 60 out
Printer speed	
Terminals	Yes
Other	Analog to digital converter, communications interfaces

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

Texas Instruments TI-980A (continued)

COMMENTS: In COMBAT GRANDE, 28 of these systems were used as display console controllers, 2 as primary and backup display system controllers and 7 at the individual long range radar sites as a data extractor controller.

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

The following information is generalized data based on manufacturer's specifications. This equipment is used in the ESD system(s) cited in the comments, though configuration may actually vary.

MANUFACTURER & MODEL

UNIVAC AN/UYK-7

<u>DATA FORMAT</u>	
Word length (bits)	32
Fixed point operand (bits)	8, 16, 32, or 64
Instruction length (bits)	16 or 32
Floating point	8, 16, 32, or 64
<u>MAIN STORAGE</u>	
Type	Magnetic core (or thin film)
Cycle time (microseconds)	1.5 (down to 0.75 effective rate for overlapping requests to thin film)
Capacity (words)	3 increments internally, up to 13 external increments of shared memory.
Increments (words)	16K (32K)
Interleaving	2 level (optional)
Buffer (cache) storage	No
Extended memory	No
<u>CENTRAL PROCESSOR</u>	
CPU configuration	1 to 3 CPU multiprocessors
Registers	2 sets of 19 bit index, 8 - 32 bit accumulators, 2 sets of 8 - 18 bit base (addressable only in interrupt mode), 1 - 23 bit status, 1 - 18 bit breakpoint, 1 - 20 bit address, 82 integrated circuit registers used for CPU control memory
No. directly addressable words	
Indirect addressing	One level
Machine cycle time	
Instruction time (microseconds)	Add 1.5 (1.2), multiply 7.5 (7.5), divide 14.5 (14.5), shift 1.75 (1.75)
Hardware functional units	None
Real-time clock or timer	Standard
<u>INPUT/OUTPUT CONTROL</u>	
I/O word size (bits)	32 bit parallel (or optional bit serial)
Maximum I/O rate (words/second)	167K per channel
No. external interrupt levels	28 types of interrupts in 4 levels
Number I/O channels	Up to 16, all computer to computer capable
<u>PERIPHERAL EQUIPMENT</u>	
Disc pack storage	8, 16, or 32M bit per handler, 17 millisecond access
Non-interchangeable disc storage	No
Drum storage	No

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

UNIVAC AN/UYK-7 (continued)

PERIPHERAL EQUIPMENT (continued)	
Magnetic tape	7 or 9 track, 800 or 1600 bits per inch, 120 inches per second
Punched card	Read 600 cards per minute, punch 75
Paper tape	Read 300 characters per second, punch 75
Printer speed	132 characters per line, 400 lines per minute
Terminals	Synchronous or asynchronous
Other	Navy Tactical Data System (NTDS) interface North Atlantic Treaty Organization (NATO) standard interface (development). All the above peripherals are militarized or ruggedized; higher speed commercial peripherals are available for use in a non-hostile environment.

COMMENTS: Used in TACSI as data processing and display computers.

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

The following information is generalized data based on manufacturer's specifications. This equipment is used in the ESD system(s) cited in the comments, though configuration may actually vary.

MANUFACTURER & MODEL	UNIVAC AN/UYK-20 (U-1600)
<u>DATA FORMAT</u>	
Word length (bits)	16
Fixed point operand (bits)	16
Instruction length (bits)	16 or 32 bit
Floating point	Yes
<u>MAIN STORAGE</u>	
Type	Magnetic core
Cycle time (microseconds)	0.75 read and restore
Capacity (words)	32K (512K with new memory system)
Increments (words)	8K (32K with new memory system)
Interleaving	
Buffer (cache) storage	No
Extended memory	No
<u>CENTRAL PROCESSOR</u>	
CPU configuration	
Registers	4 page address, 16 or 32 high-speed general purpose, 2 program status
No. directly addressable words	65K
Indirect addressing	One level
Machine cycle time	
Instruction time (microseconds)	Add .84, shift 1.0, multiply 3.6, divide 6.6
Hardware functional units	Microprogrammed controller, Math Pack: microprogrammed ROM square root, trigonometric and hyperbolic functions, floating point, double precision multiply or divide, 512 words of user defined micro-memory
Real-time clock or timer	Standard
<u>INPUT/OUTPUT CONTROL</u>	
I/O word size (bits)	Variable up to 16 bit
Maximum I/O rate (words/second)	1M (combined rate)
No. external interrupt levels	3 level
Number I/O channels	16 combined serial and parrallel
<u>PERIPHERAL EQUIPMENT</u>	
Disc pack storage	8, 16, or 32M bit, 17 millisecond access
Non-interchangeable disc storage	No
Drum storage	No
Magnetic tape	7 or 9 track, 800 or 1600 bits per inch, 120 inches per second

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

UNIVAC AN/UYK-20 (U-1600) (continued)

PERIPHERAL EQUIPMENT (continued)	
Punched card	Read 600 cards per minute, punch 75
Paper tape	Read 300 characters per second, punch 75
Printer speed	132 characters per line, 400 lines per minute
Terminals	Synchronous to 9600 bits per second, asynchronous to 2400 bits per second
Other	Navy Tactical Data System (NTDS) interface, VACALES (USMC tactical data system) interface, North Atlantic Treaty Organization (NATO) standard interface (development.)
All of the above peripherals are militarized or ruggedized; higher speed commercial peripherals are available for use in a non-hostile environment.	

COMMENTS: U-1600 is the Air Force designation for this computer.
 2 U-1600's are used in CONUS Over-the-Horizon Backscatter Radar; Combat Theater Communications uses 1 as a central processor. The AN/UYK-20 is used in the Joint Tactical Information Distribution System as a translator processor.

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

The following information is generalized data based on manufacturer's specifications. This equipment is used in the ESD system(s) cited in the comments, though configuration may actually vary.

MANUFACTURER & MODEL

UNIVAC U-1108

<u>DATA FORMAT</u>	
Word length (bits)	36
Fixed point operand (bits)	12 or 18 or 36 or 72
Instruction length (bits)	36
Floating point	Yes
<u>MAIN STORAGE</u>	
Type	Magnetic core
Cycle time (microseconds)	0.75
Capacity (words)	65K to 262K
Increments (words)	65K
Interleaving	Standard
Buffer (cache) storage	
Extended memory	No
<u>CENTRAL PROCESSOR</u>	
CPU configuration	1 to 3
Registers	128 125 nanosecond integrated circuit control registers, 15 index, 16 accumulators, 8 unassigned, 1 each: repeat count, mask processor state
No. directly addressable words	16M words with register extended addressing
Indirect addressing	Any desired level
Machine cycle time	Register time 125 microseconds
Instruction time (microseconds)	Fixed add 0.75, long add 1.63, fixed multiply 2.38, fixed divide 10.13, store 0.75
Hardware functional units	
Real-time clock or timer	Yes
<u>INPUT/OUTPUT CONTROL</u>	
I/O word size (bits)	36
Maximum I/O rate (words/second)	
No. external interrupt levels	
Number I/O channels	Up to 16, each channel can handle up to 16 devices
<u>PERIPHERAL EQUIPMENT</u>	
Disc pack storage	Up to 8 drives per controller, 26M words per drive
Non-interchangeable disc storage	Up to 366M words
Drum storage	Up to 8 drums per controller, up to 33M words per drum

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

UNIVAC U-1108 (continued)

PERIPHERAL EQUIPMENT (continued)	
Magnetic tape	7 or 9 track, up to 200 inches per second, up to 1600 bits per inch, up to 16 handlers per system
Punched card	Up to 1000 cards per minute in, 300 out
Paper tape	
Printer speed	Up to 1600 lines per minute
Terminals	TTY, CRT, synchronous/asynchronous
Other	

COMMENTS: Used in COBRA DANE at the FTD for post mission analysis.

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

The following information is generalized data based on manufacturer's specifications. This equipment is used in the ESD system(s) cited in the comments, though configuration may actually vary.

MANUFACTURER & MODEL

UNIVAC U-1110

DATA FORMAT

Word length (bits)	36
Fixed point operand (bits)	12 or 18 or 36 or 72
Instruction length (bits)	36
Floating point	Yes

MAIN STORAGE

Type	Plated wire
Cycle time (microseconds)	Read 0.32, write 0.52
Capacity (words)	32K to 262K
Increments (words)	32K
Interleaving	Standard
Buffer (cache) storage	
Extended memory	Magnetic core, 131K to 1M, 0.75 or 1.5 microsecond cycle time, optional interleaving

CENTRAL PROCESSOR

CPU configuration	1 to 4 multiprocessor
Registers	112 75 nanosecond integrated circuit control registers, 15 index, 16 accumulator, 1 each: repeat, mask, real-time clock, several unassigned fast-access temporary storage.
No. directly addressable words	262K (4 processor) and 1048K of extended stores
Indirect addressing	Any desired level
Machine cycle time	Register time 75 nanoseconds
Instruction time (microseconds)	Fixed add 0.3, fixed multiply 1.5, fixed divide 6.4, store 0.3
Hardware functional units	
Real-time clock or timer	Yes

INPUT/OUTPUT CONTROL

I/O word size (bits)	36
Maximum I/O rate (words/second)	4M
No. external interrupt levels	
Number I/O channels	Up to 24, each channel can handle up to 16 devices

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

UNIVAC U-1110 (continued)

PERIPHERAL EQUIPMENT (continued)	
Disc pack storage	26M words per drive, up to 8 drives per controller
Non-interchangeable disc storage	Up to 366M words
Drum storage	Up to 8 drums per controller, up to 33M words per drum
Magnetic tape	7 or 9 track, up to 200 inches per second, up to 1600 bits per inch, up to 16 handlers per system
Punched card	Up to 1000 cards per minute in, 300 out
Paper tape	
Printer speed	Up to 1600 lines per minute
Terminals	TTY, CRT, synchronous/asynchronous
Other	

COMMENTS: Has a 4 deep instruction stack for lookahead and concurrency. One of these systems was used in CONUS Over-the-Horizon Backscatter Radar.

GENERALIZED COMPUTER EQUIPMENT SPECIFICATIONS

The following information is generalized data based on manufacturer's specifications. This equipment is used in the ESD system(s) cited in the comments, though configuration may actually vary.

MANUFACTURER & MODEL

UNIVAC U-1616

<u>DATA FORMAT</u>	
Word length (bits)	16 + 2 (parity)
Fixed point operand (bits)	8 or 16 or 32
Instruction length (bits)	16 or 32
Floating point	
<u>MAIN STORAGE</u>	
Type	Magnetic core
Cycle time (microseconds)	0.75
Capacity (words)	8K to 65K
Increments (words)	
Interleaving	
Buffer (cache) storage	
Extended memory	
<u>CENTRAL PROCESSOR</u>	
CPU configuration	Single processor
Registers	16 to 64 accumulators
No. directly addressable words	65K
Indirect addressing	One level
Machine cycle time	
Instruction time (microseconds)	Full word add 1.0
Hardware functional units	Optional: multiply and divide; standard: byte manipulation, literal instructions
Real-time clock or timer	Optional
<u>INPUT/OUTPUT CONTROL</u>	
I/O word size (bits)	8 or 16 or 32
Maximum I/O rate (words/second)	1.3M
No. external interrupt levels	8
Number I/O channels	
<u>PERIPHERAL EQUIPMENT</u>	
Disc pack storage	Yes
Non-interchangeable disc storage	Yes
Drum storage	No
Magnetic tape	200K characters per second maximum speed
Punched card	200 cards per minute in; 75 out
Paper tape	200 characters per second in; 75 out
Printer speed	
Terminals	TTY, CRT
Other	

COMMENTS: Two of these systems were used in CONUS OTH-B.

TAB B SIZING AND TIMING PARAMETERS

1.0 INTRODUCTION

This Tab contains eleven sets of sizing and timing relationships that have been developed through analytical techniques (also see Analytical Techniques in Tab A of Volume I of this handbook). The graphics are presented to illustrate the types of relationships that can be developed by analytical techniques and to demonstrate the relative trends in computer system sizing and timing parameters. Although these graphs were created specifically for this handbook, the algorithms upon which many were based were developed during the past several years. In addition, some of the algorithms were derived through analysis of data that dated back to 1969. One must acknowledge that during the past decade there has been considerable advancement in computer science technology that would impact on the sizing and timing relationships illustrated, such as the increased speed and density of storage, and the advent of modern programming techniques. Accordingly, users of this handbook are cautioned not to consider the relationships illustrated in this tab as anything more than additional possible data points that might be considered in the overall evaluation of a computer system's sizing and timing parameters. It is suggested that the relationships illustrated, as well as many others, could be made viable by the engineers and computer scientists of ESD/TOI through data collection and analyses of sizing and timing parameters pertaining to recently completed or current ESD projects.

1.1 Derivation of Relationships.

The derivations of relationships presented in this Tab are discussed in the following sections and Tab B introductory pages.

1.1.1 Tabs B.1. through B.5 (pages B-7 through B-40). These relationships, regarding memory size and cycle times, were derived from an algorithm developed by Doty Associates 3/ in 1977 and are based on the analysis of data obtained from a study sponsored by the Office of the

Secretary of Defense, and performed by the Johns Hopkins University Applied Physics Laboratory 4/. Although the data contained deficiencies, the following algorithm was developed using multivariate regression:

$$M = \left[\frac{N_F^{0.337} W_S^{0.147}}{t_C^{0.770}} \right] e^{0.177+k} \quad (\text{Equation 1})$$

where

M = Memory size in thousands of words of object code

N_F = Number of major functions to be performed by the software.

W_S = Word size in bits

t_C = Cycle time of processor in microseconds

k = A constant dependent on application

where k equals:

- 2.573 for signal processing
- 2.727 for missile fire control
- 2.781 for interfacing
- 3.412 for communication
- 3.565 for navigation
- 4.046 for command and control
- 4.451 for weapon fire control

NOTE: $R^2 = 0.52$

R^2 is the coefficient of determination and is a measure of how well the data points fit the curve, with the better the fit the closer R^2 is to a value of 1.0.

Perhaps the variable N_F , major function, is best defined by examples, such as; communications, target tracking, target identification, navigation, system monitoring, display, steering, parameter measurement, tuning, target data entry, firing sequence control, etc. This would include operating system functions. W_S and t_C are essentially dictated by the CPU in the computer system. Based on the type of application, most of which are in real-time, few overlays would be

expected. If the core utilization is assumed to be approximately 80 percent, the algorithm could be considered for estimating software size.

By varying different aspects of the algorithm, various relationships were developed.

1.1.2 Tab B.6 (pages B-41 through B-44). This set of relationships is based on queuing theory. The curves illustrate the relationships among the number of Input/Output (I/O) terminals, the probable response time depending on the CPU service time, and the interval between terminal messages.

1.1.3 Tab B.7 (pages B-45 through B-47). This set of curves illustrates the relationship between the number of lines of source instructions to be developed and the number of months required to develop them. The curves are based on two research efforts conducted by Walston 5/ and Graver 2/ in 1977. Walston developed the following algorithm:

$$M = 4.1 \left[I^{0.36} \right] \quad (\text{Equation 2})$$

Where

M = Months of effort required to develop software.

I = Total number of delivered lines of source code (excluding comments) in thousands.

Graver developed a number of algorithms as part of an initial software costing model, one of which included a multiplier based on core utilization:

$$F_u = \frac{0.7}{1 - \sqrt{P - 0.5}} \quad (\text{Equation 3})$$

Where

F_u = Multiplier based on core utilization.

P = Percent of core utilized.

From the above equation, DAI derived:

$$F_u' = F_u^{0.28} \quad (\text{Equation 4})$$

Where

$$F_u' = \text{A factor for core utilization}$$

Equation 4 was then combined with Equation 2 to produce Equation 5 and the relationships illustrated in Tab B regarding the impact of core utilization on months of development time:

$$M = 4.1F_u' \left[I^{0.36} \right] \quad (\text{Equation 5})$$

Use of the above algorithm (Equation 5) demonstrates that increased core utilization does impact on development time, however, it does not appear to demonstrate that as core utilization approaches 100 percent the development time should increase exponentially due to both core constraint and size of the developmental software package. It is hypothesized that a more accurate algorithm would be as follows:

$$M = 4.1F_u' \left[I^{0.36 + kf(P)} \right] \quad (\text{Equation 6})$$

However, the exponent, $kf(P)$ needs to be defined.

1.1.4 Tab B.8 (pages B-48 through B-50). The manmonths of software development time vs core utilizations relationships in Tabs B.8.1 and B.8.2 were developed by combining another algorithm by Doty Associates with F_u' cited in Equation 4 above:

$$MM = 4.089F_u' \left[I^{1.263} \right] \quad (\text{Equation 7})$$

Where

MM = Manmonths of effort required to develop software.

I = Total number of delivered lines of source code (excluding comments) in thousands.

1.1.5 Tabs B.9 through B.11 (pages B-51 through B-58). These relative relationships involving fast storage capacity requirements, air targets tracked, and air target speeds were based on the application of algorithms developed by Frederic 1/ in 1974, that are presented below:

A. For fighter targets

$$S_f = 14.30T^{1.05} \quad (\text{Equation 8})$$

Where

S_f = Total words (in thousands) in fast storage (storage units with retrieval rates in the order of a thousand times faster than slower storage such as random access vice sequential access).

T = number of targets being tracked.

B. For helicopter targets

$$S_f = 8.30T^{1.05} \quad (\text{Equation 9})$$

C. For fighter targets

$$O_i = 14T^{1.51} \quad (\text{Equation 10})$$

Where

O_i = Total operating instructions (in thousands).

D. For helicopter targets

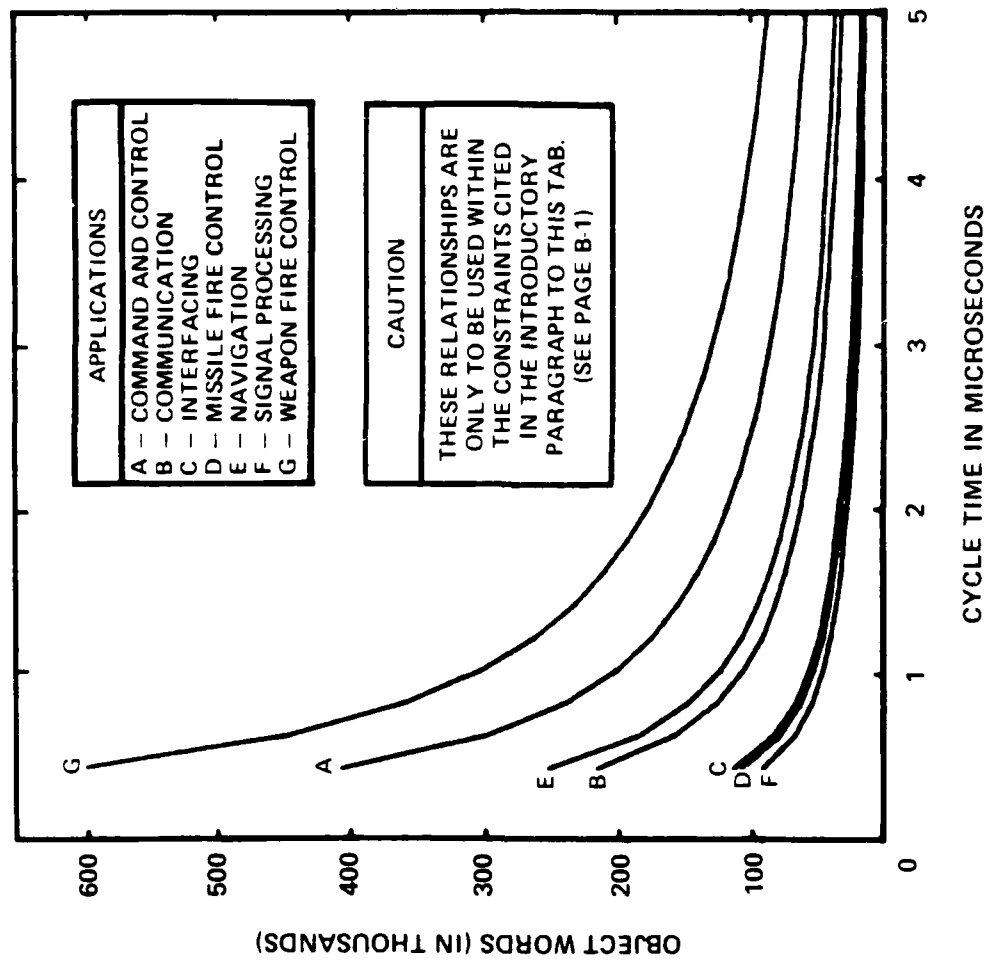
$$O_i = 10T^{1.51} \quad (\text{Equation 11})$$

TAB B.1 APPLICATIONS VS. CYCLE TIME

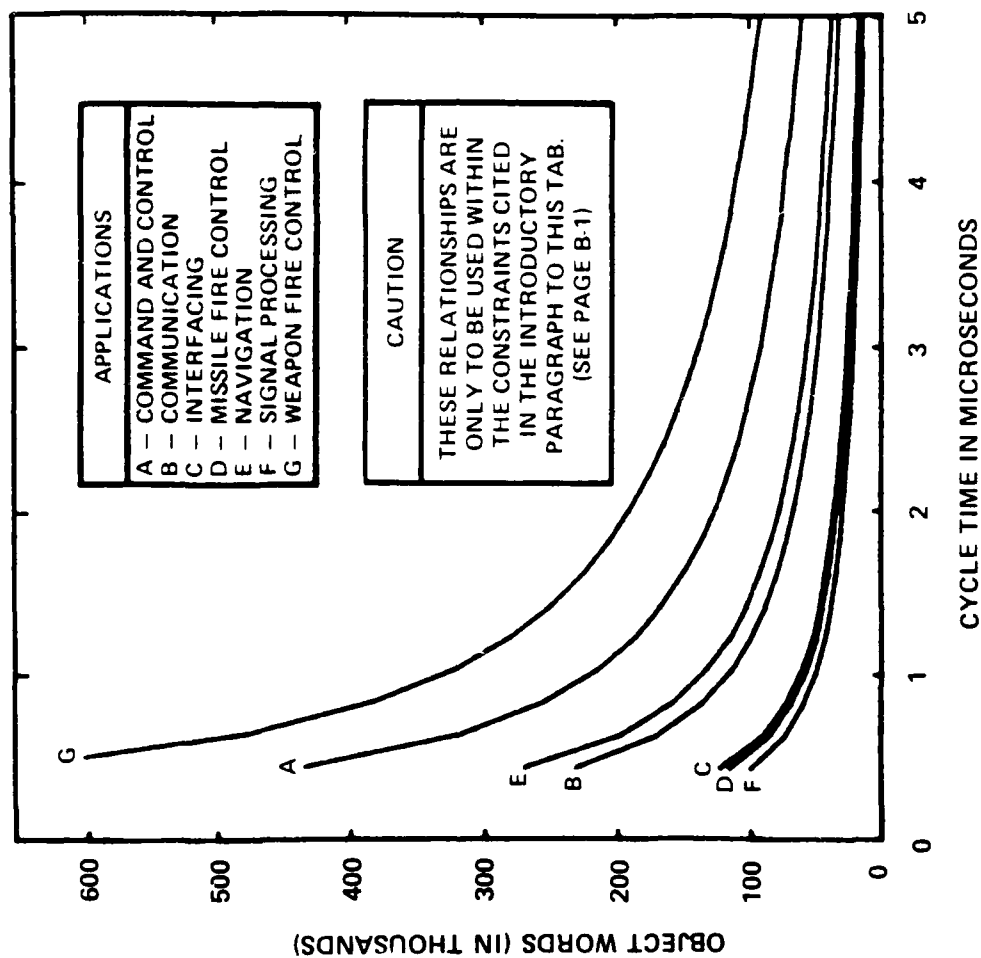
The relationships, illustrated in this set of Tabs, B.1.1 through B.1.6, were developed through the application of the algorithm (Equation 1) discussed in Tab B, Section 1.1.1. These curves illustrate the relationship between CPU cycle time, major system applications, word size and total words of object code, not necessarily core resident. The general relationship is that the faster the CPU, the larger the size of software in object words. The effect becomes dramatic for CPUs with cycle time less than 1.5 microseconds.

APPLICATIONS VS. CYCLE TIME

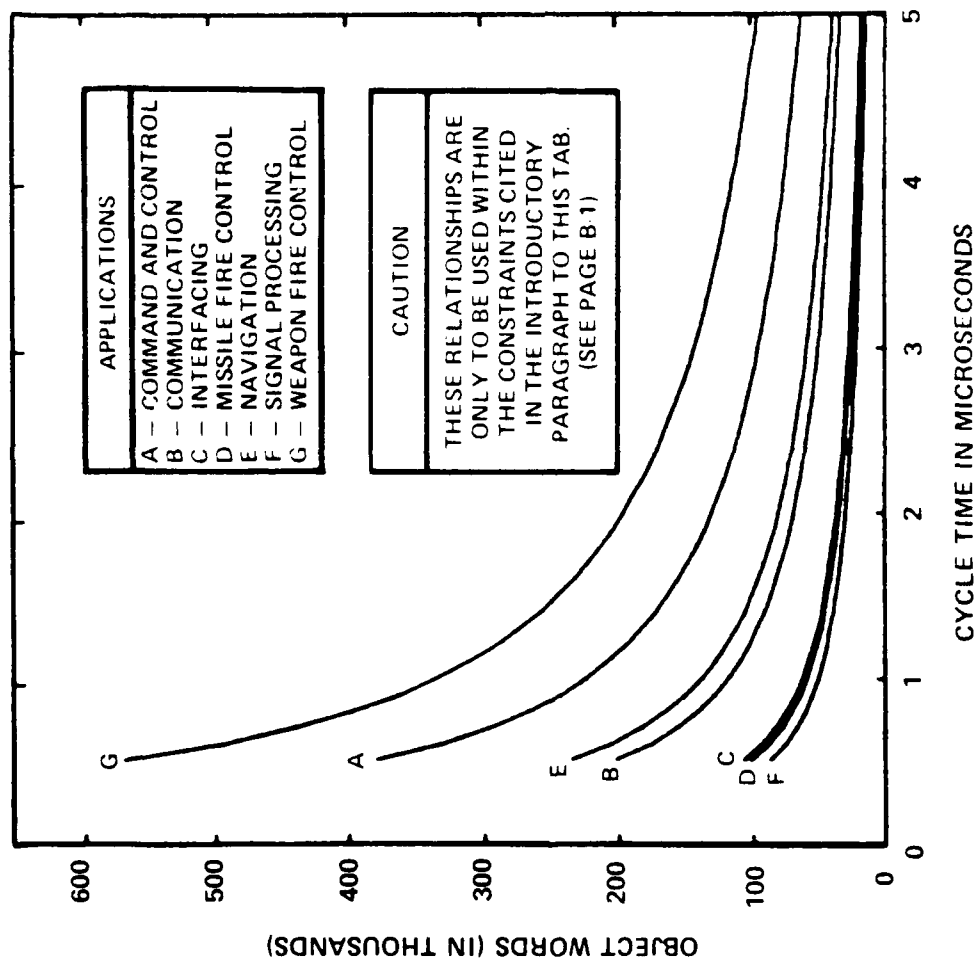
<u>Tab</u>		<u>Page</u>
B.1.1	8 bits/word size	B- 8
B.1.2	12 bits/word size	B- 9
B.1.3	16 bits/word size	B-10
B.1.4	24 bits/word size	B-11
B.1.5	32 bits/word size	B-12
B.1.6	64 bits/word size	B-13



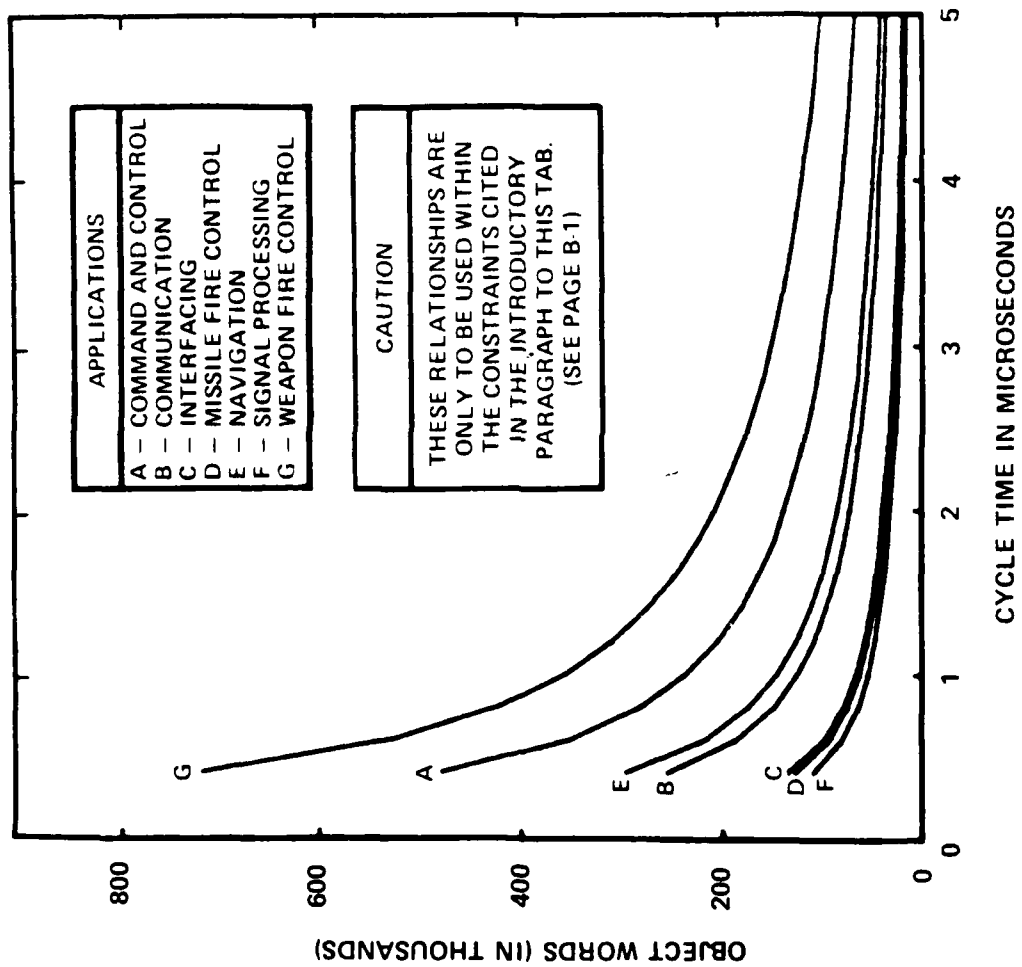
TAB B.1.1 APPLICATION VS CYCLE TIME
(8 BITS/WORD SIZE)



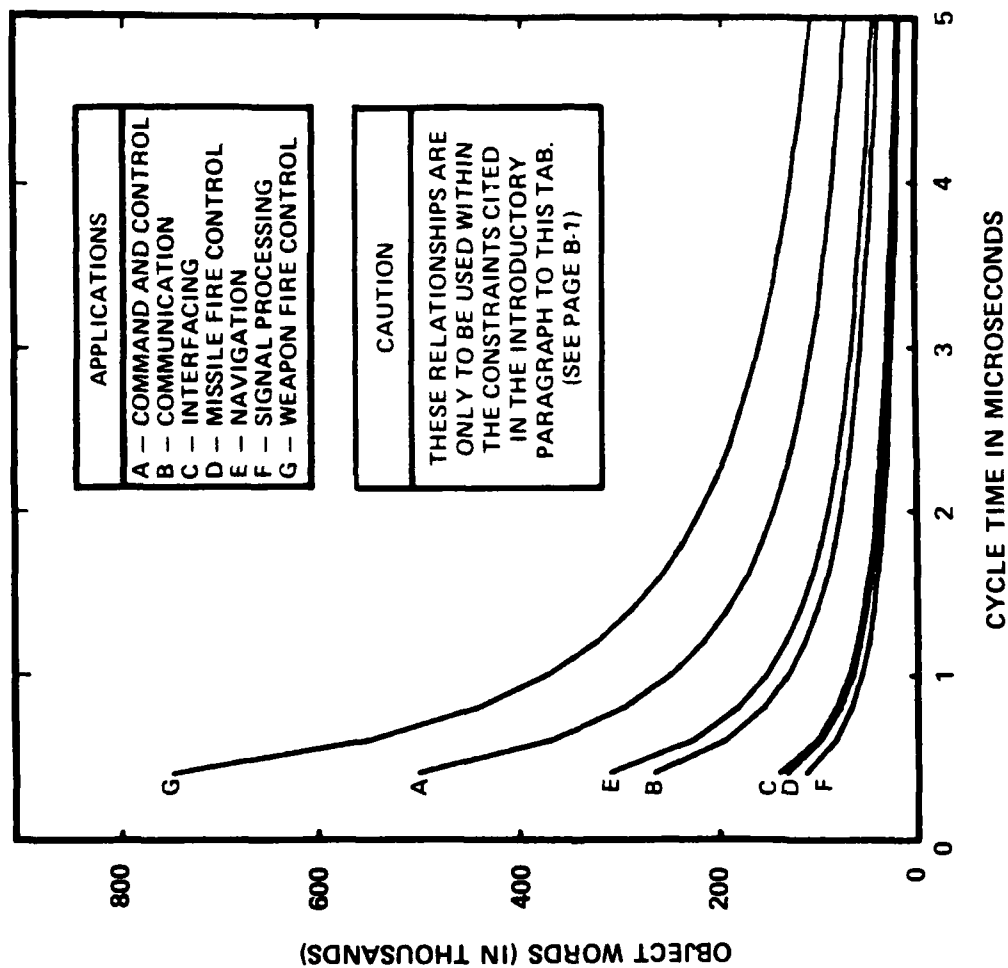
TAB B.1.2 APPLICATION VS CYCLE TIME
(12 BITS/WORD SIZE)



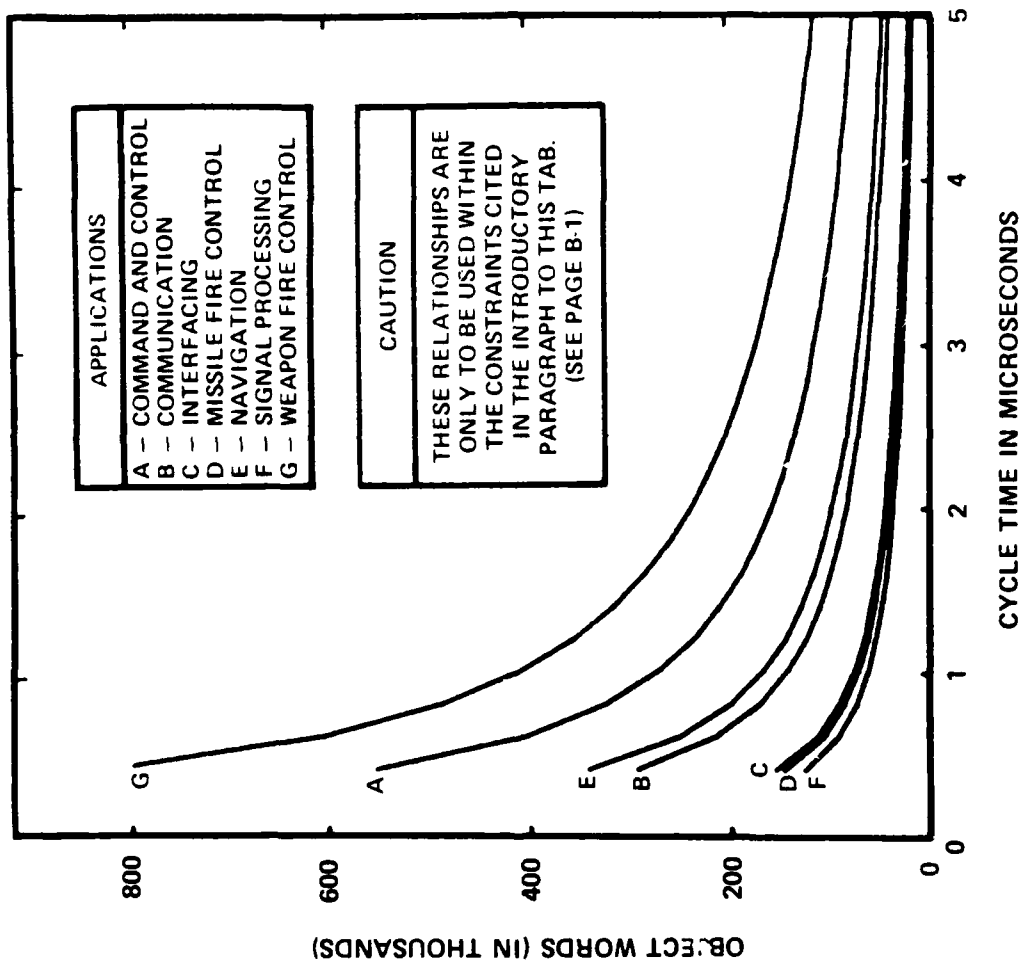
TAB B.1.3 APPLICATION VS CYCLE TIME
(16 BITS/WORD SIZE)



TAB B.1.4 APPLICATION VS CYCLE TIME
(24 BITS/WORD SIZE)



TAB B.1.5 APPLICATION VS CYCLE TIME
(32 BITS/WORD SIZE)



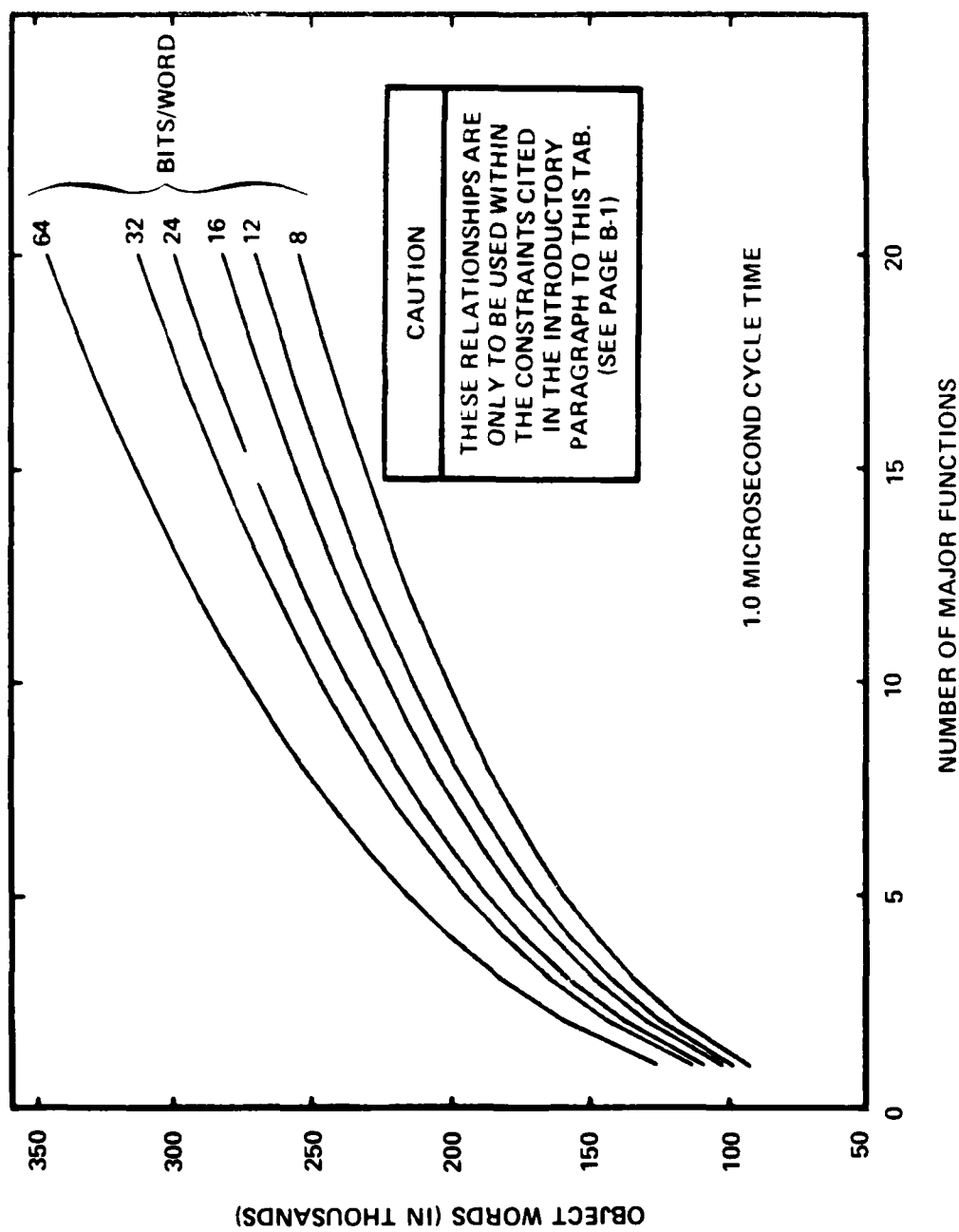
TAB B.1.6 APPLICATION VS CYCLE TIME
(64 BITS/WORD SIZE)

TAB B.2 OBJECT WORDS VS. THE NUMBER OF MAJOR FUNCTIONS

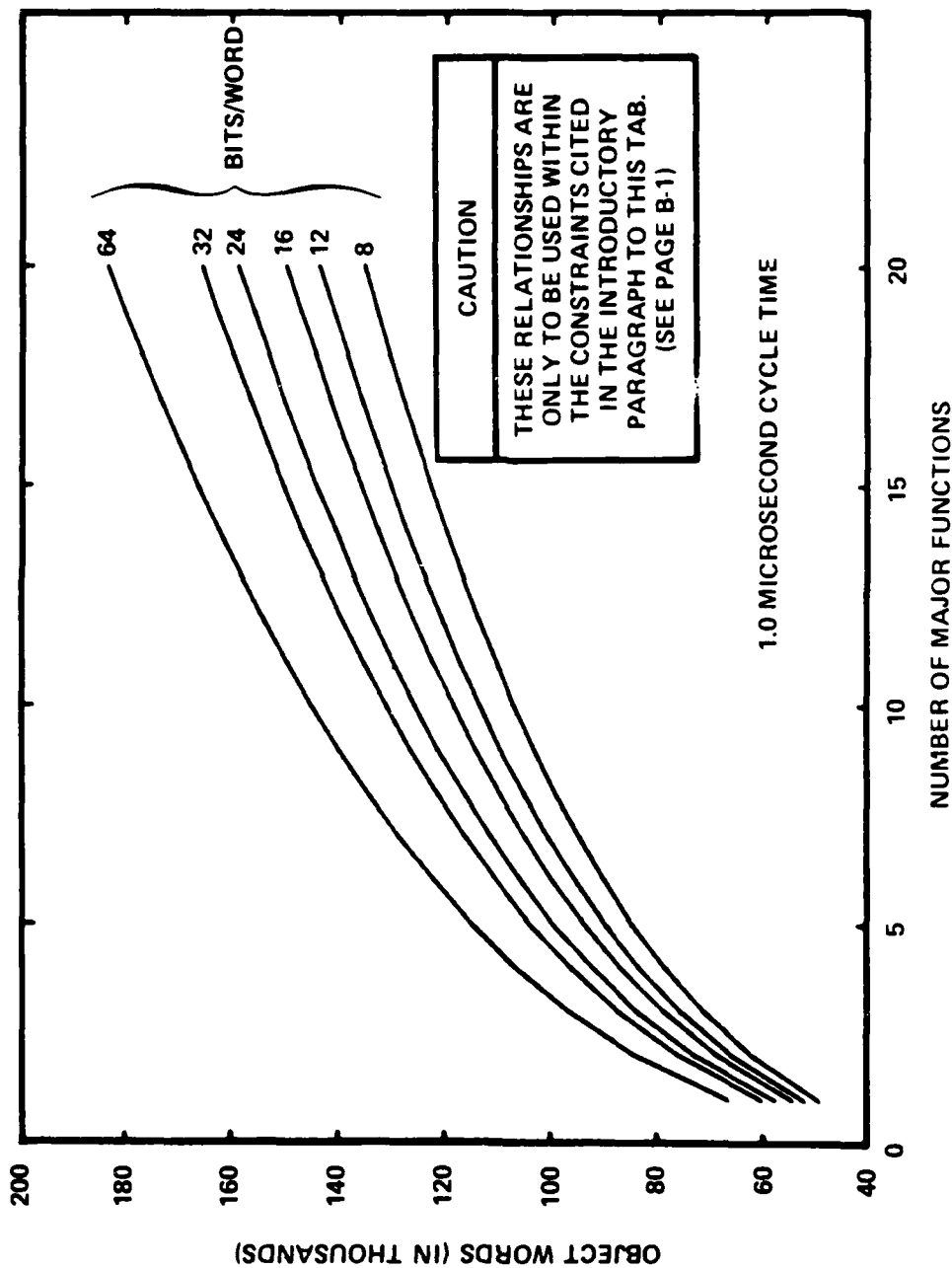
The relationships, illustrated in this set of Tabs, B.2.1 through B.2.7, were developed through the application of the algorithm (Equation 1) discussed in Tab B, Section 1.1.1. These curves relate initial estimates of total object words to the number of major functions within a system application. In addition, word size and CPU cycle time are displayed. Major functions in this context are considered primary actions that must be executed by the software to accomplish its C³ mission requirements, such as target tracking, target identification, navigation, etc.

OBJECT WORDS VS. THE NUMBER OF MAJOR FUNCTIONS (1.0 micro-second cycle time)

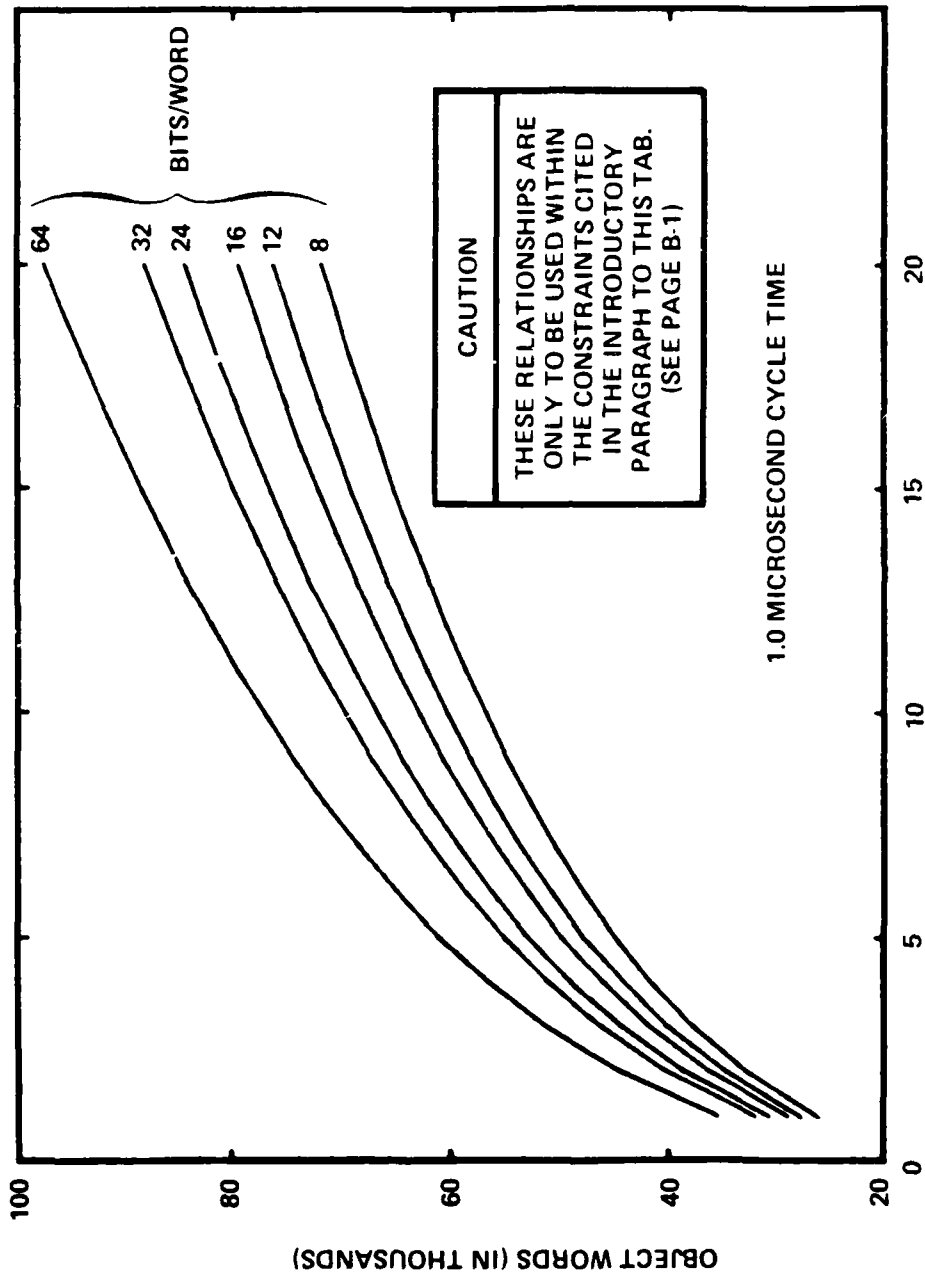
<u>Tab</u>	<u>Page</u>
B.2.1 COMMAND AND CONTROL	B-15
B.2.2 COMMUNICATION	B-16
B.2.3 INTERFACING	B-17
B.2.4 MISSILE FIRE CONTROL.	B-18
B.2.5 NAVIGATION.	B-19
B.2.6 SIGNAL PROCESSING	B-20
B.2.7 WEAPON FIRE CONTROL	B-21



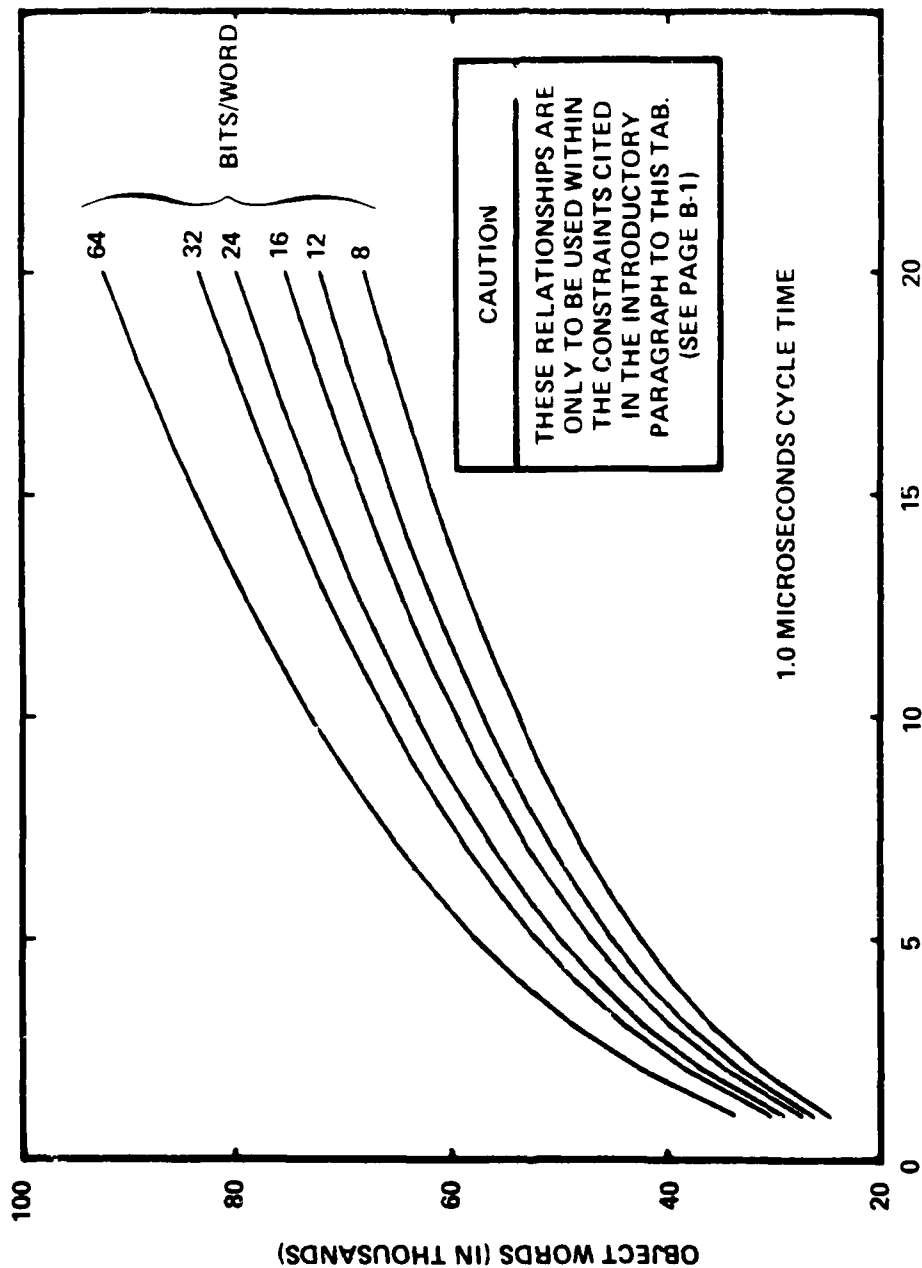
TAB B.2.1 OBJECT WORDS VS THE NUMBER OF MAJOR FUNCTIONS (COMMAND AND CONTROL)



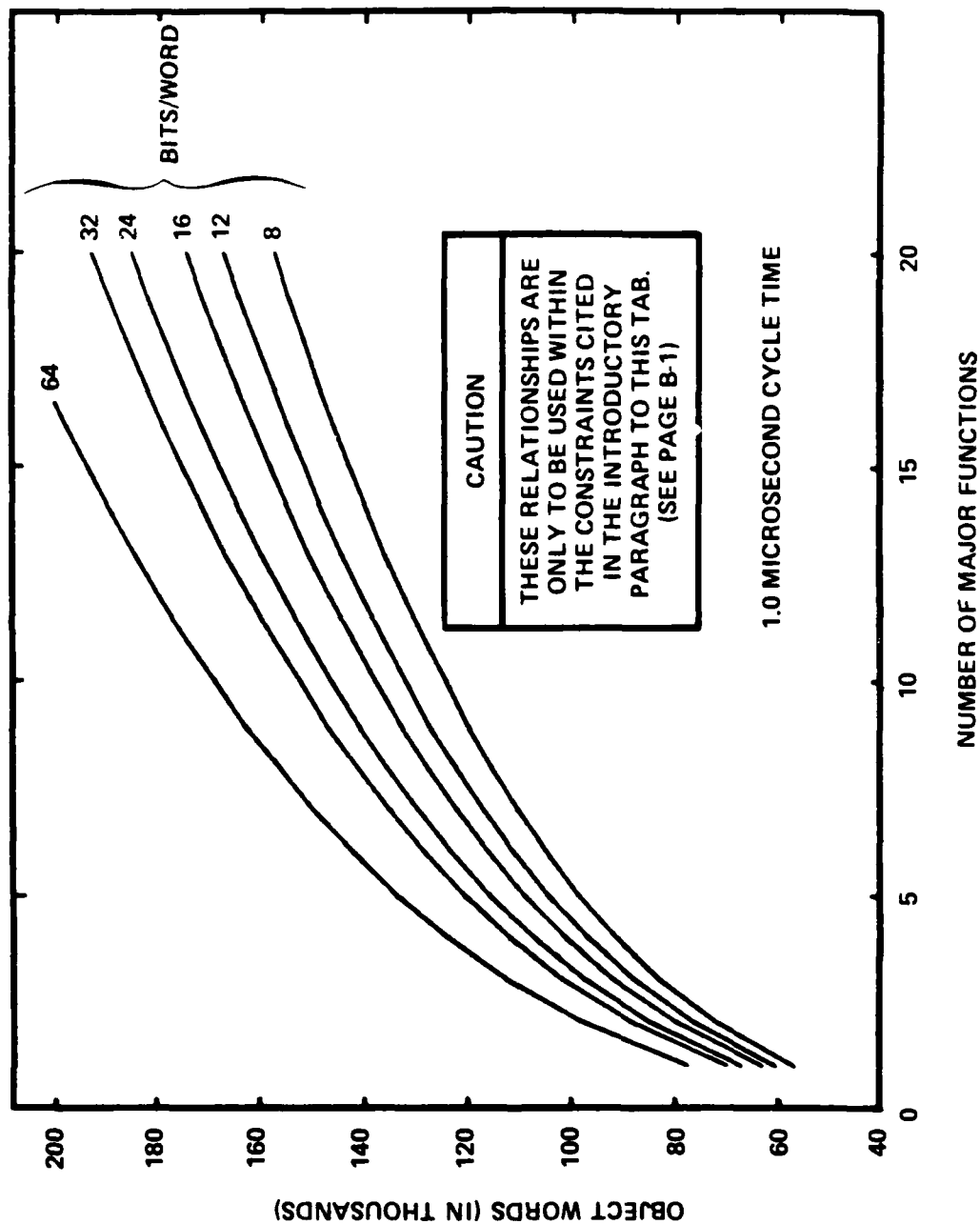
TAB B.2.2 OBJECT WORDS VS THE NUMBER OF MAJOR FUNCTIONS (COMMUNICATION)



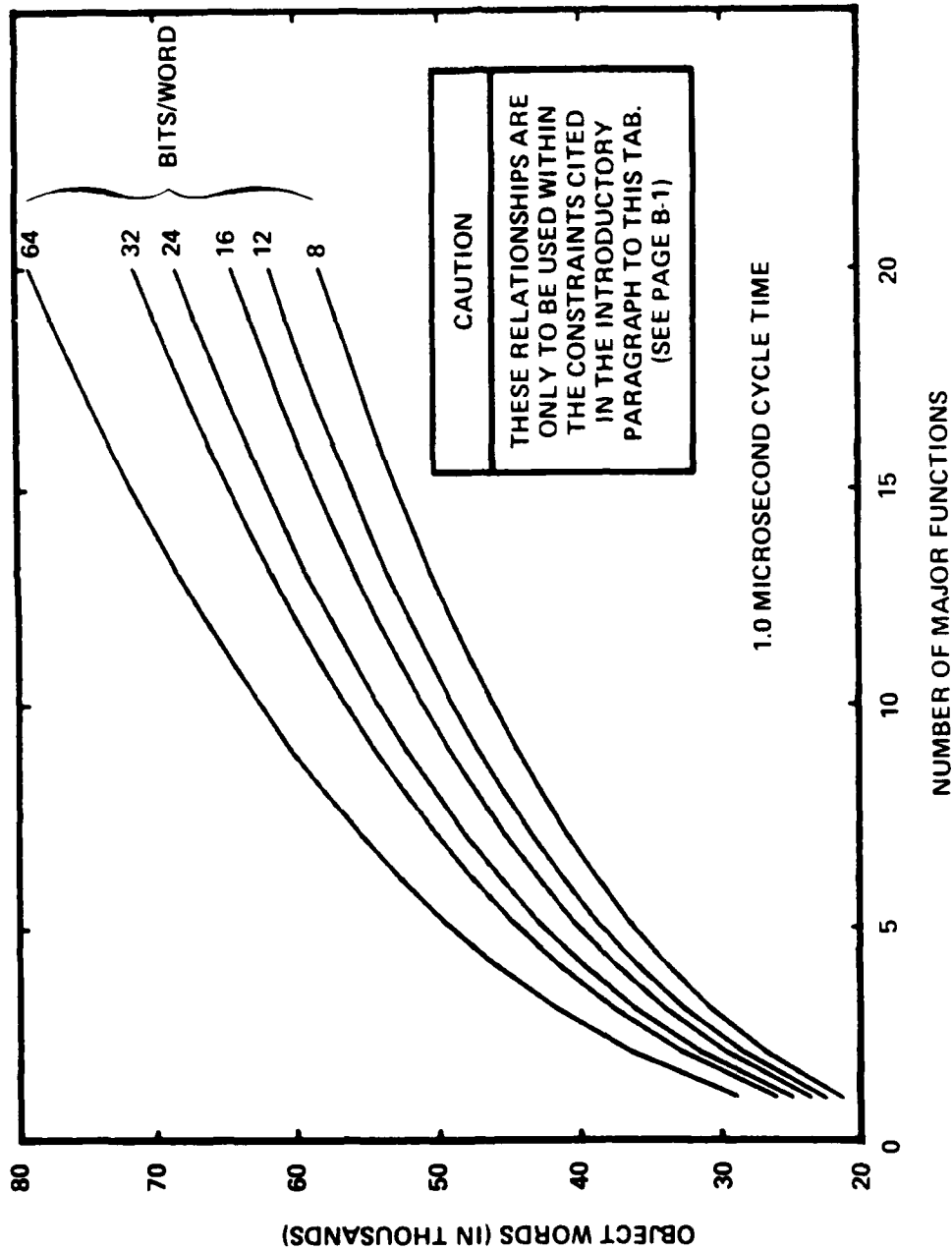
TAB B.2.3 OBJECT WORDS VS THE NUMBER OF MAJOR FUNCTIONS (INTERFACING)



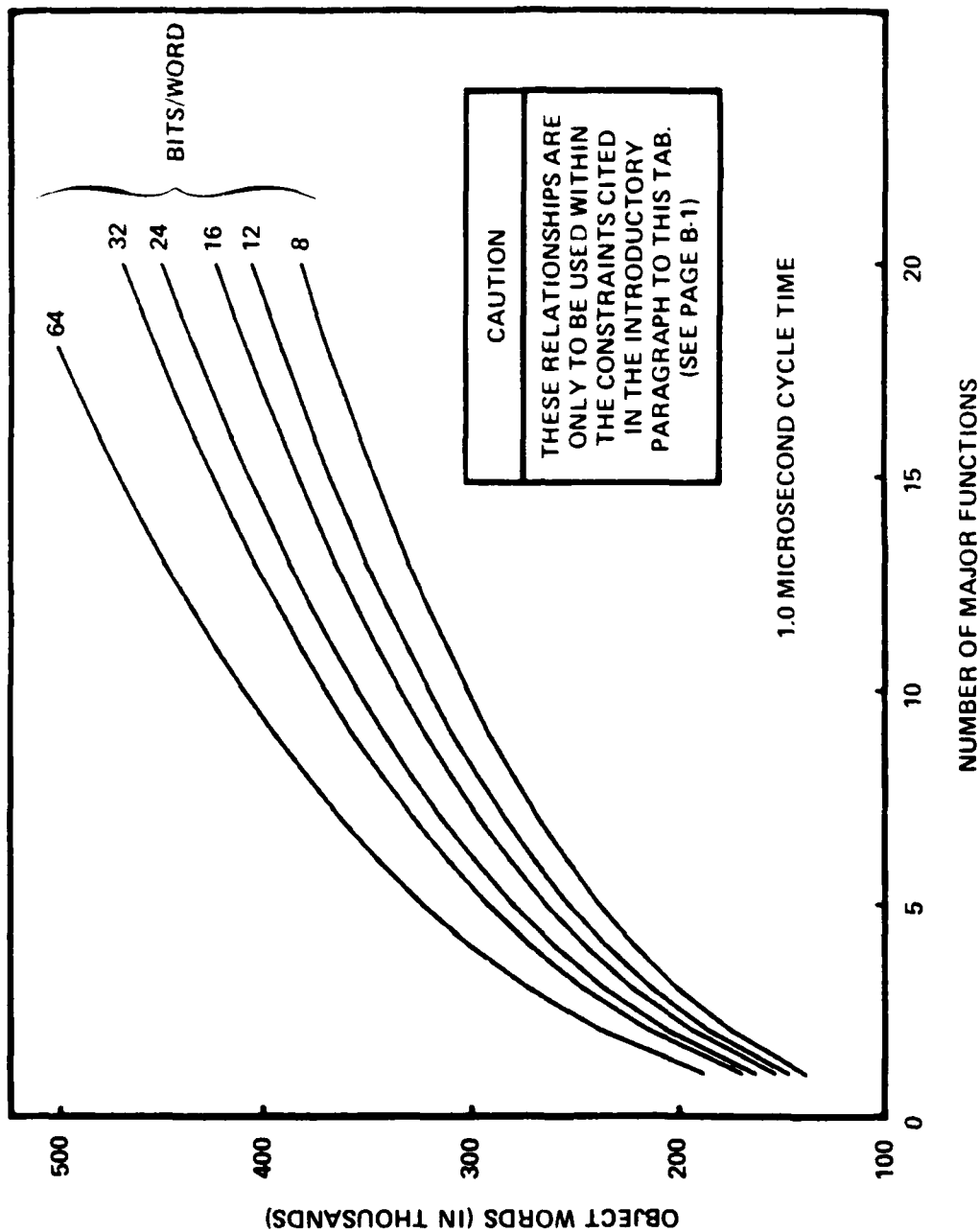
TAB B.2.4 OBJECT WORDS VS THE NUMBER OF MAJOR FUNCTIONS
(MISSILE FIRE CONTROL)



TAB B.2.5 OBJECT WORDS VS THE NUMBER OF MAJOR FUNCTIONS (NAVIGATION)



TAB B.2.6 OBJECT WORDS VS THE NUMBER OF MAJOR FUNCTIONS (SIGNAL PROCESSING)

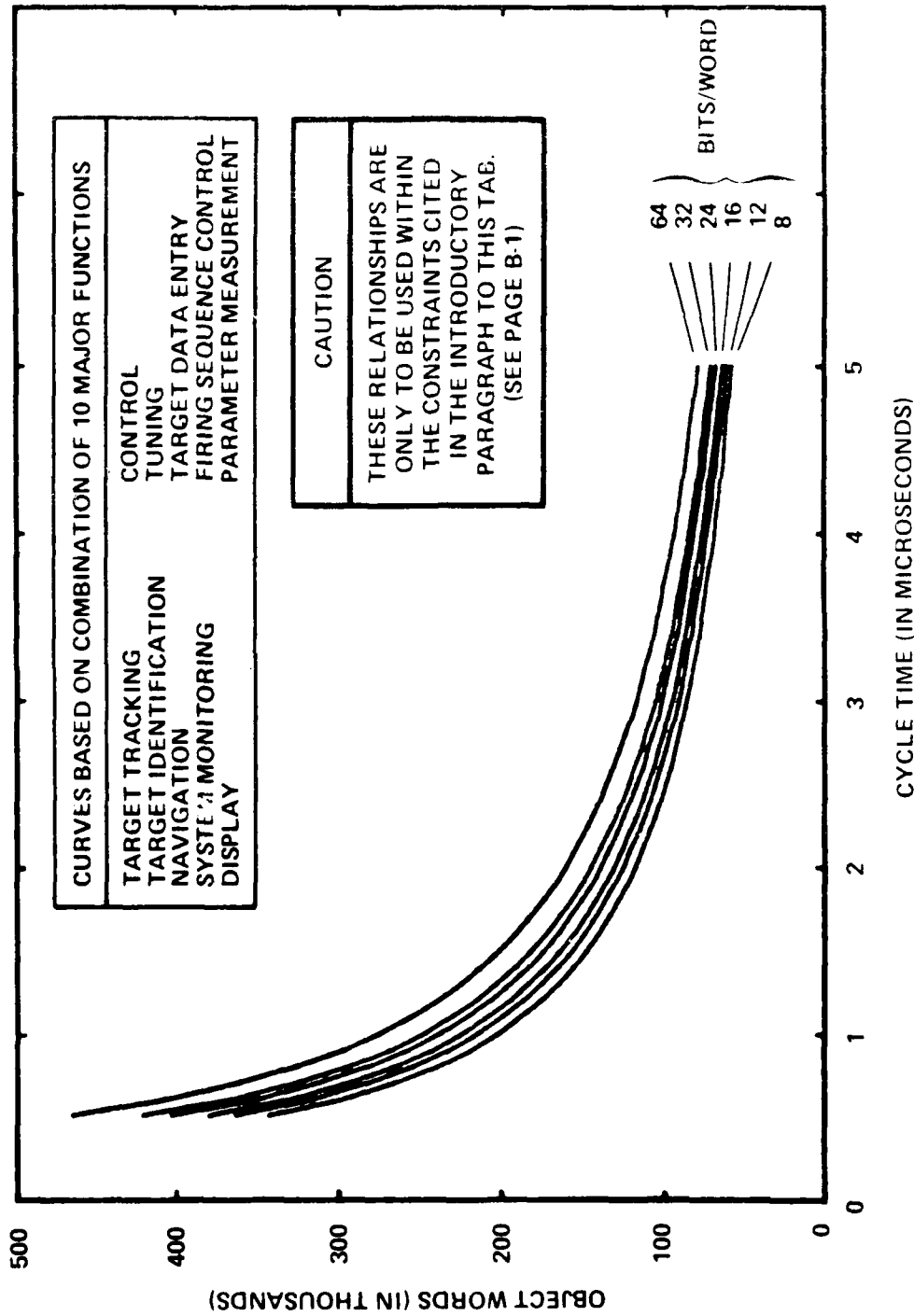


TAB B.2.7 OBJECT WORDS VS THE NUMBER OF MAJOR FUNCTIONS (WEAPON FIRE CONTROL)

TAB B.3 WORD SIZE VS. CYCLE TIME

The relationships illustrated in this Tab, B.3.1, were developed through the application of the algorithm (Equation 1) discussed in Tab B, Section 1.1.1. These curves illustrate the relationships among word size, total object words and CPU cycle time for a combination of ten major software functions. It illustrates the insensitivity of the effect of increasing word size on total object code.

<u>Tab</u>	<u>Page</u>
B.3.1 WORD SIZE VS. CYCLE TIME	B-23



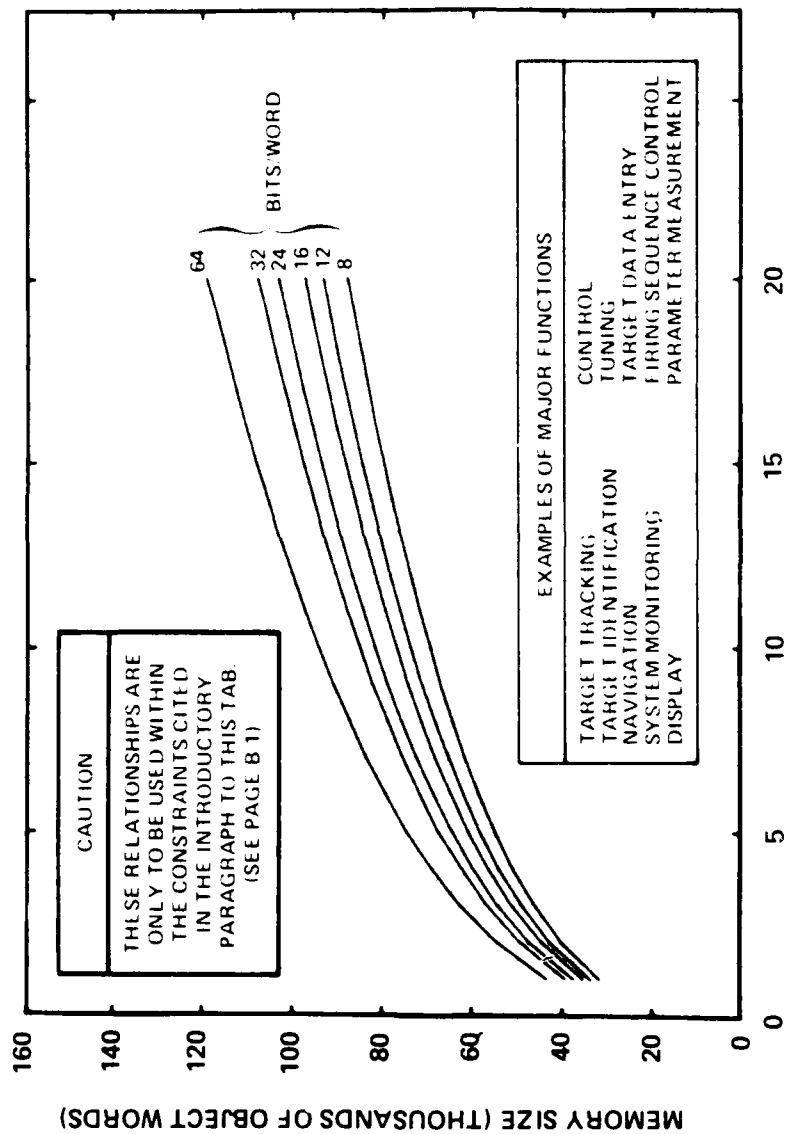
TAB B.3.1 WORD SIZE VS CYCLE TIME

TAB B.4 MEMORY SIZE VS. NUMBER OF FUNCTIONS

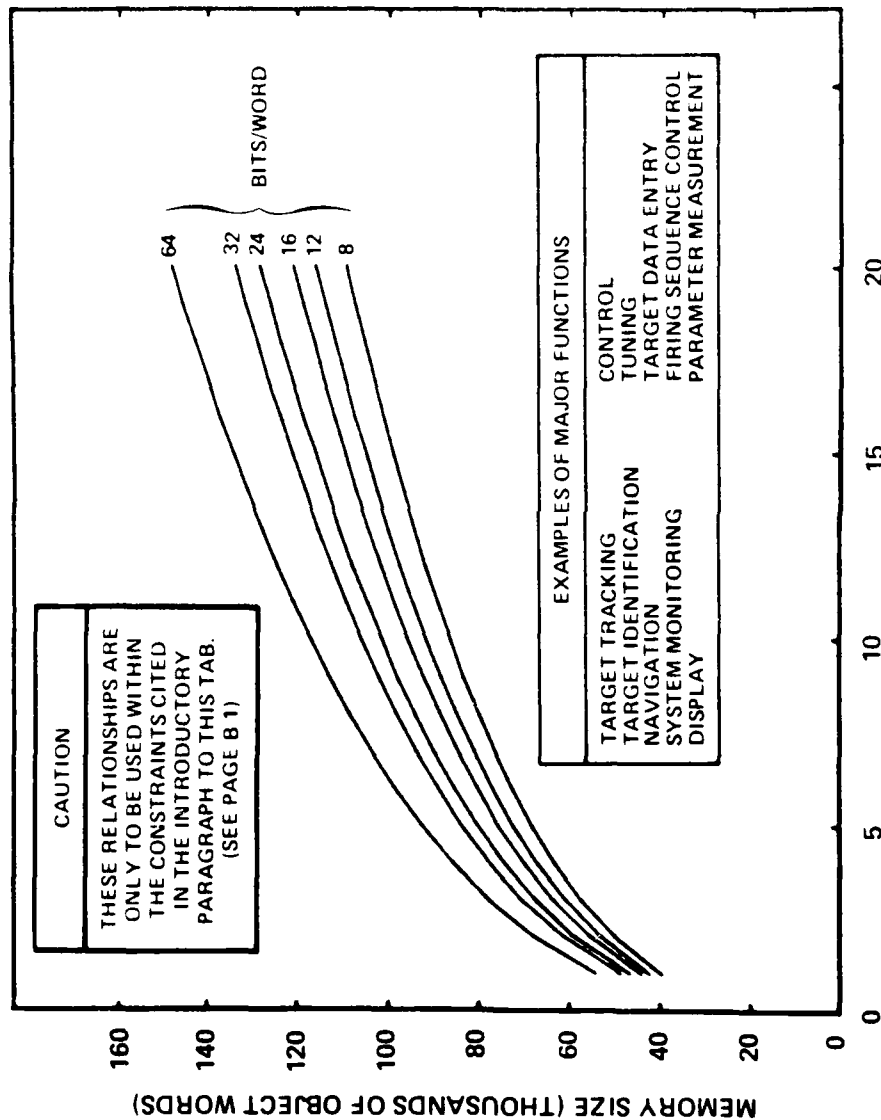
The relationships illustrated in this set of Tabs, B.4.1 through B.4.9, were developed through the application of the algorithm (Equation 1) discussed in Tab B, Section 1.1.1. These curves relate major functions, word size and memory size for different cycle times. The general relationship is that as the number of major functions increases, the memory size required increases and that larger word sizes result in the use of more memory. Curves span several CPU cycle times, from 4.0 to 0.25 microseconds. Note that as cycle time decreases, the requirement for memory size increases.

MEMORY SIZE VS. NUMBER OF FUNCTIONS

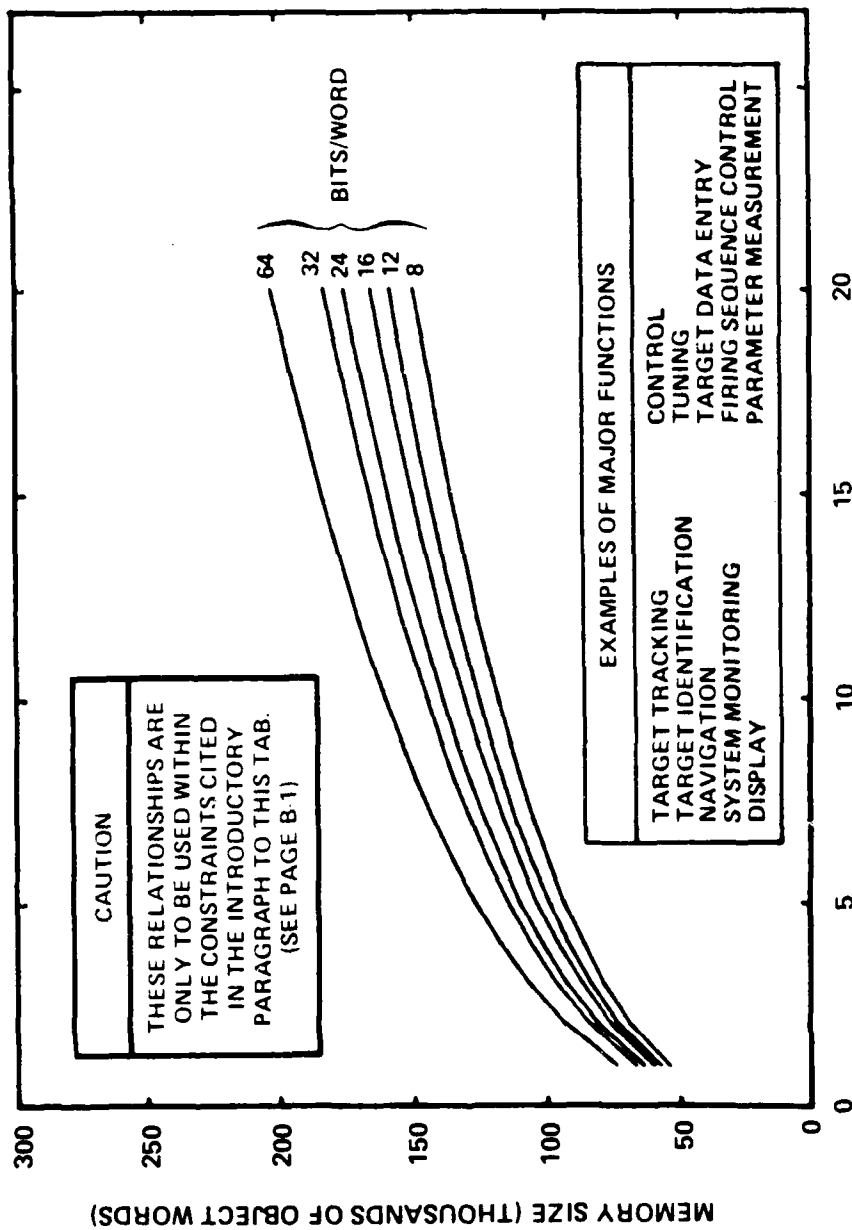
<u>Tab</u>		<u>Page</u>
B.4.1	4.0 microseconds cycle time. . . .	B-25
B.4.2	3.0 microseconds cycle time. . . .	B-26
B.4.3	2.0 microseconds cycle time. . . .	B-27
B.4.4	1.75 microseconds cycle time. . . .	B-28
B.4.5	1.5 microseconds cycle time. . . .	B-29
B.4.6	1.25 microseconds cycle time. . . .	B-30
B.4.7	1.0 microseconds cycle time. . . .	B-31
B.4.8	0.5 microseconds cycle time. . . .	B-32
B.4.9	0.25 microseconds cycle time. . . .	B-33



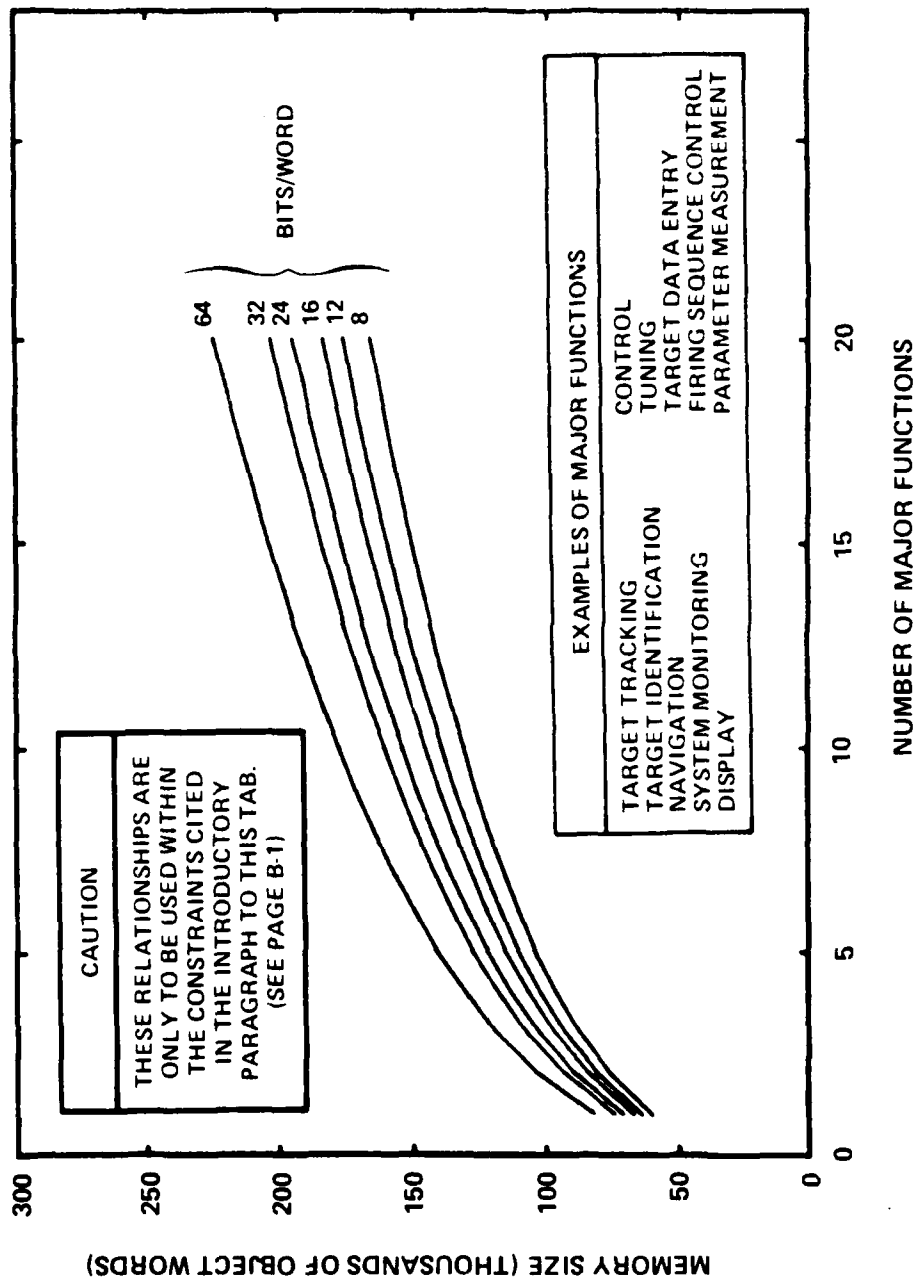
TAB B.4.1 MEMORY SIZE VS NUMBER OF FUNCTIONS
(4.0 MICROSECONDS CYCLE TIME)



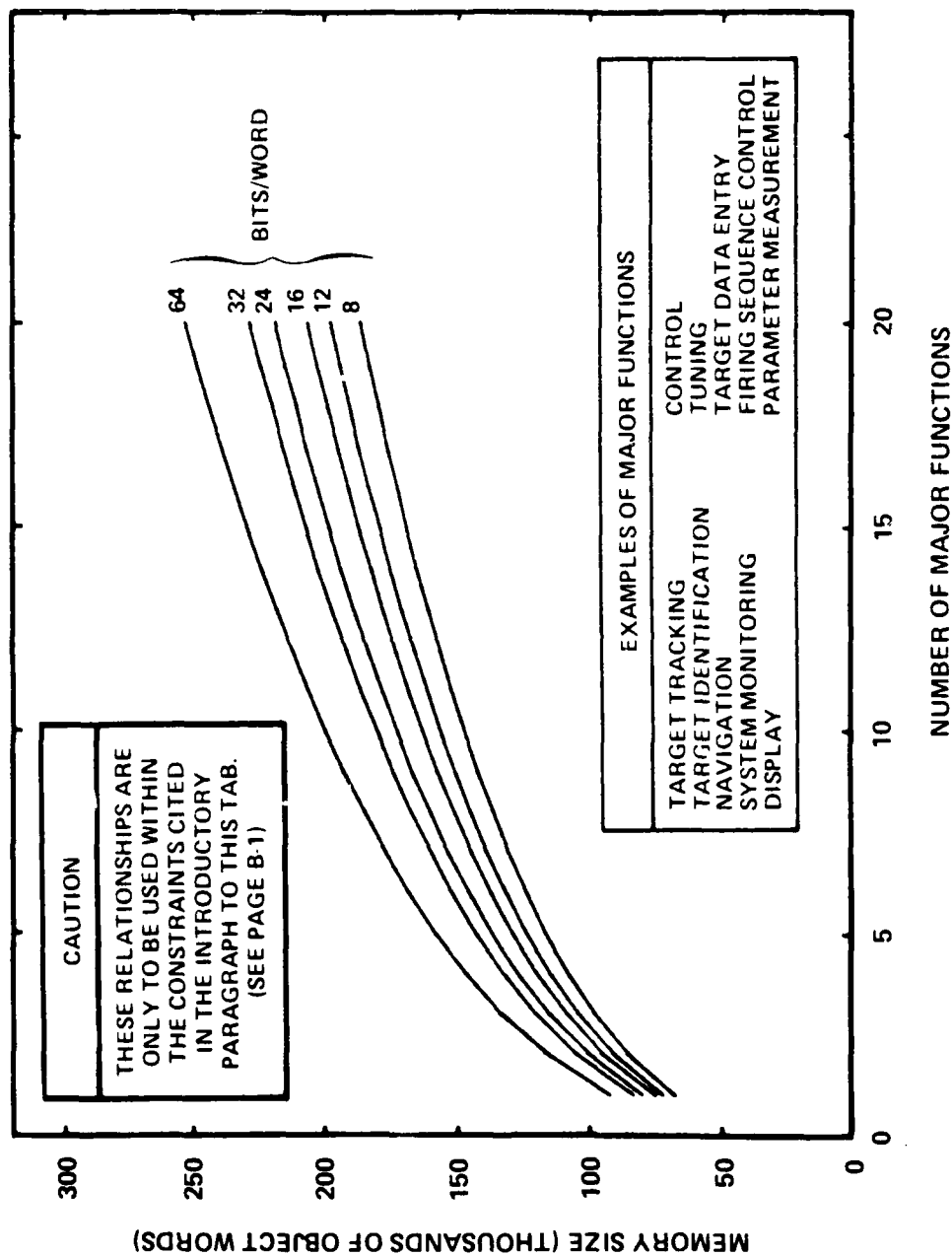
TAB B.4.2 MEMORY SIZE VS NUMBER OF FUNCTIONS
(3.0 MICROSECONDS CYCLE TIME)



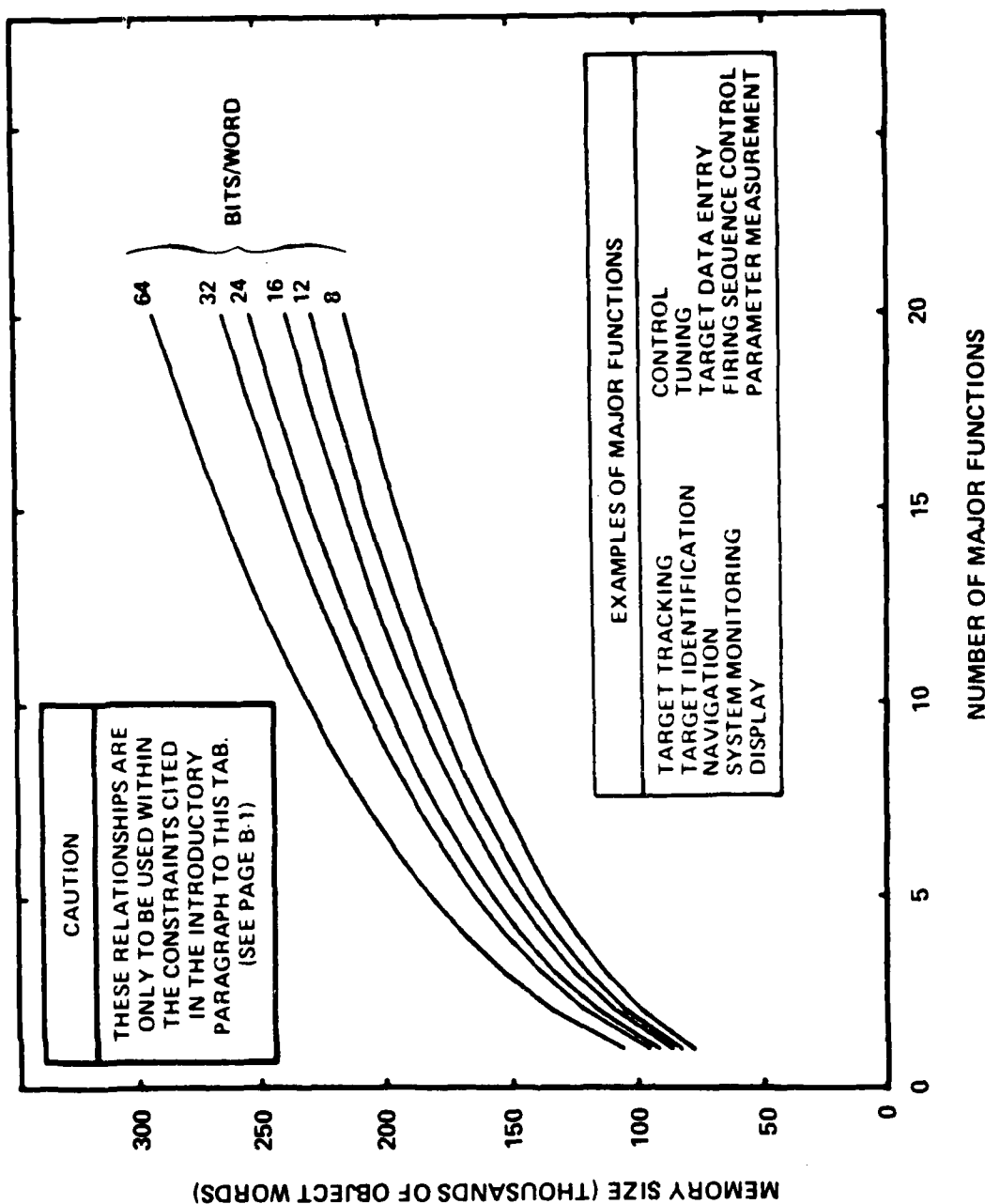
TAB B.4.3 MEMORY SIZE VS NUMBER OF FUNCTIONS (2.0 MICROSECONDS CYCLE TIME)



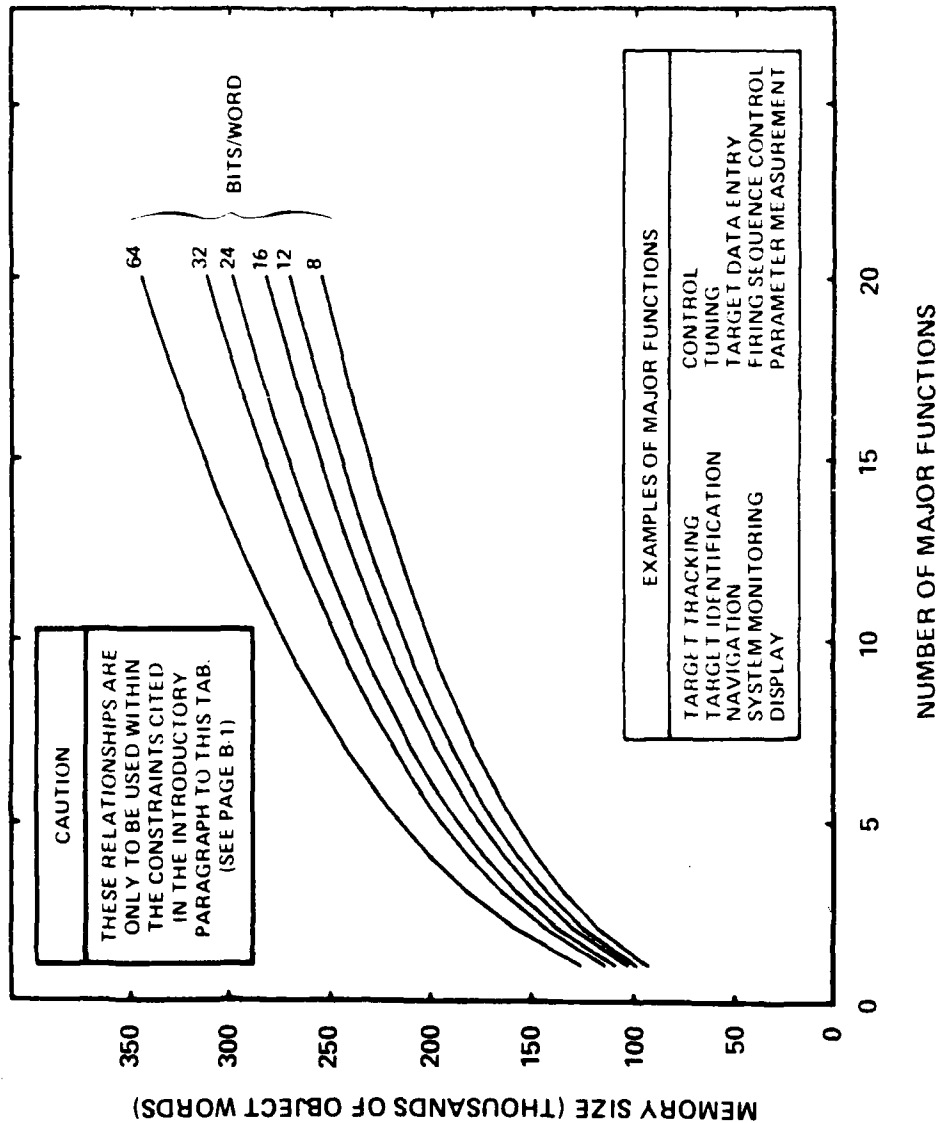
TAB B.4.4 MEMORY SIZE VS NUMBER OF FUNCTIONS
(1.75 MICROSECONDS CYCLE TIME)



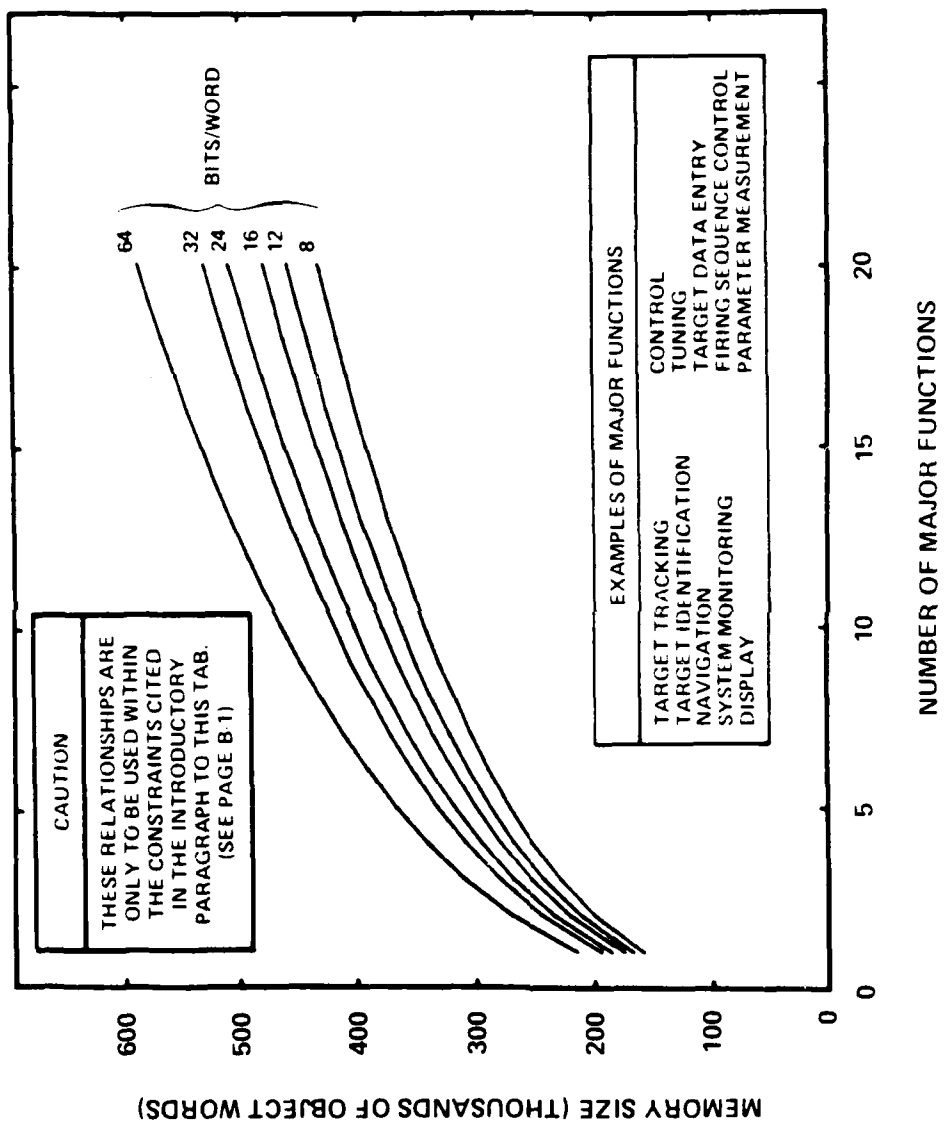
TAB B.4.5. MEMORY SIZE VS NUMBER OF FUNCTIONS
(1.5 MICROSECONDS CYCLE TIME)



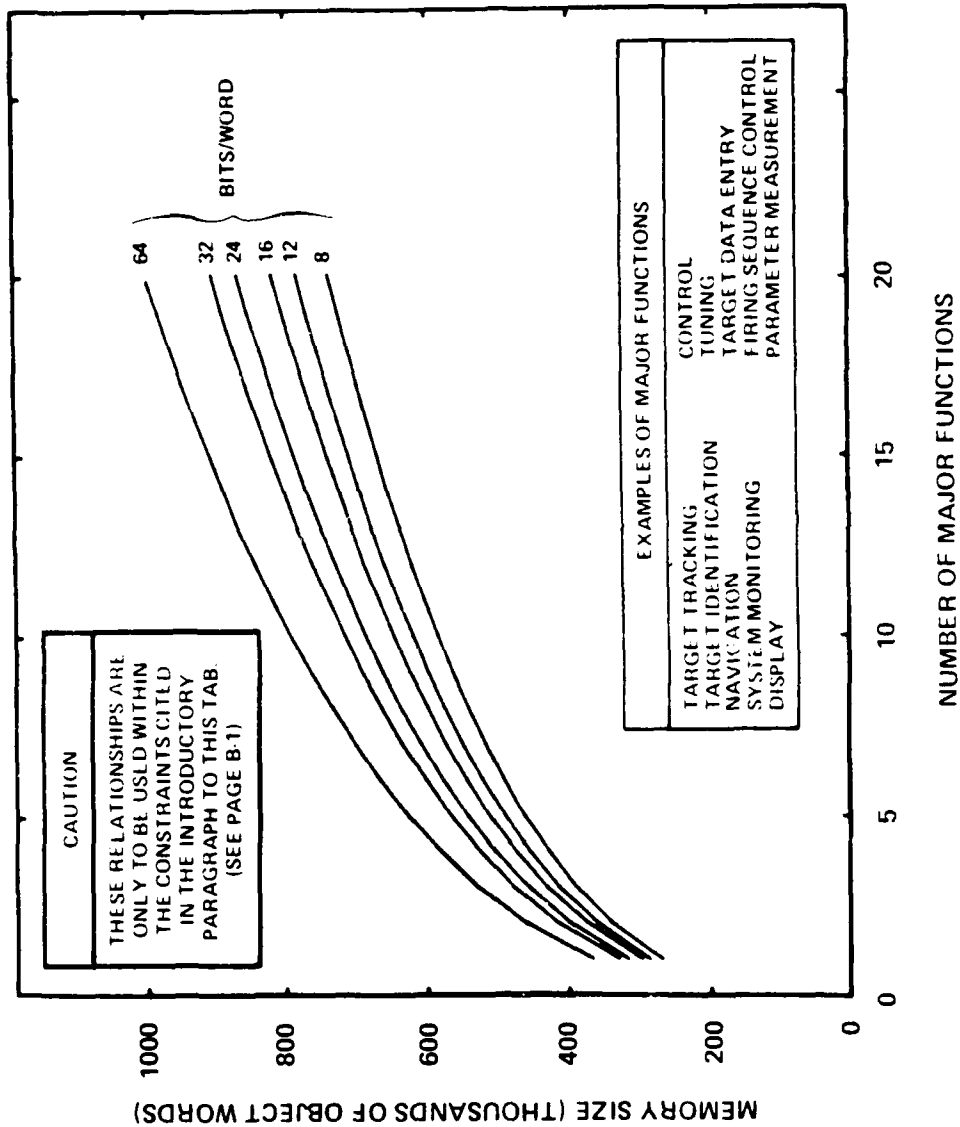
**TAB B.4.6 MEMORY SIZE VS NUMBER OF FUNCTIONS
(1.25 MICROSECONDS CYCLE TIME)**



TAB B.4.7 MEMORY SIZE VS NUMBER OF FUNCTIONS
(1.0 MICROSECONDS CYCLE TIME)



TAB B.4.8 MEMORY SIZE VS NUMBER OF FUNCTIONS
(0.5 MICROSECONDS CYCLE TIME)



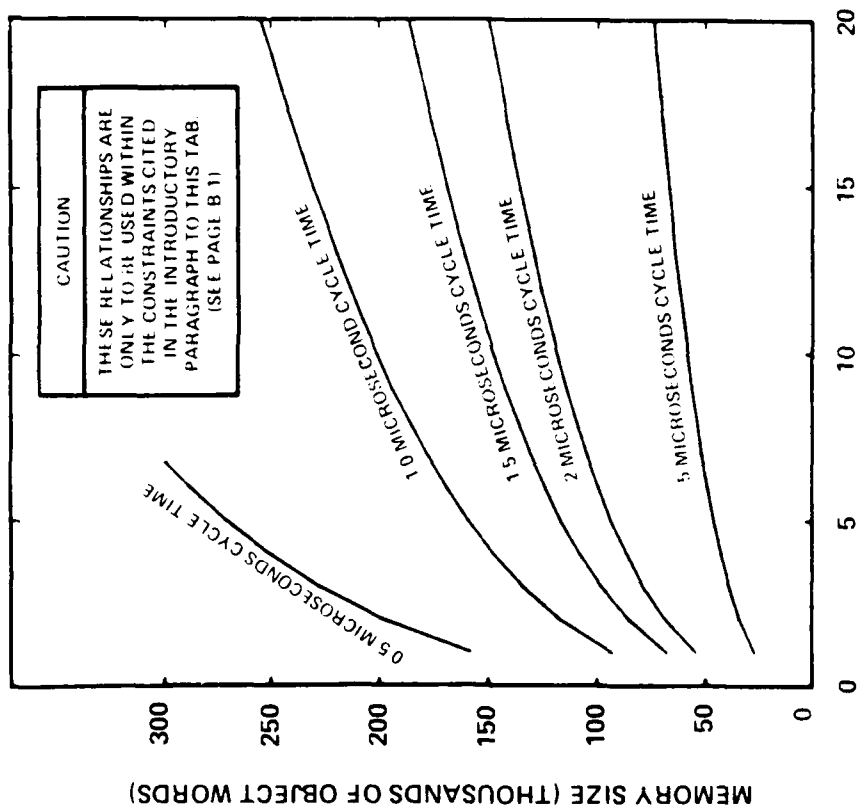
TAB B.4.9 MEMORY SIZE VS NUMBER OF FUNCTIONS
(0.25 MICROSECOND CYCLE TIME)

TAB B.5 MEMORY SIZE VS. CYCLE TIME AND
NUMBER OF FUNCTIONS

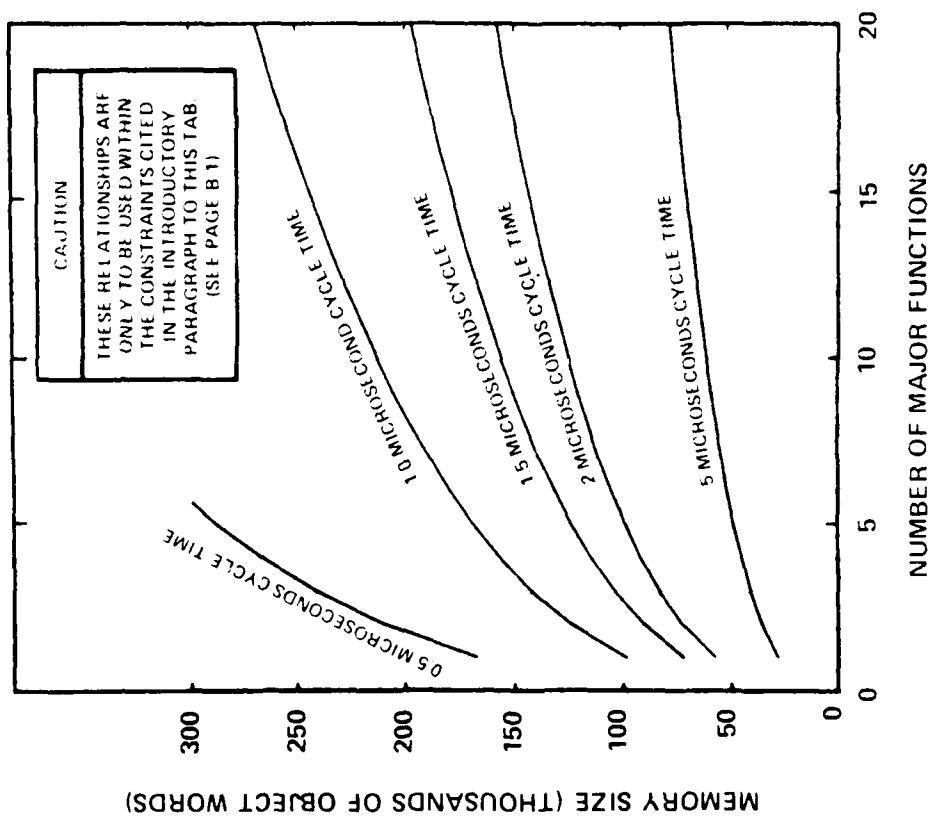
The relationships illustrated in this set of Tabs, B.5.1 through B.5.6, were developed through the application of the algorithm (Equation 1) discussed in Tab B, Section 1.1.1. These curves illustrate the relationships among memory size and major functions for various cycle times and memory word sizes. Given the cycle time and number of major functions, an estimate of memory size is given. As cycle time decreases the memory size requirement increases. As one progresses from 8 to 64 bits/word on the graphs, the demand for memory size also increases. The word sizes include 8, 12, 16, 24, 32, and 64 bits/word.

MEMORY SIZE VS. CYCLE TIME AND
NUMBER OF FUNCTIONS

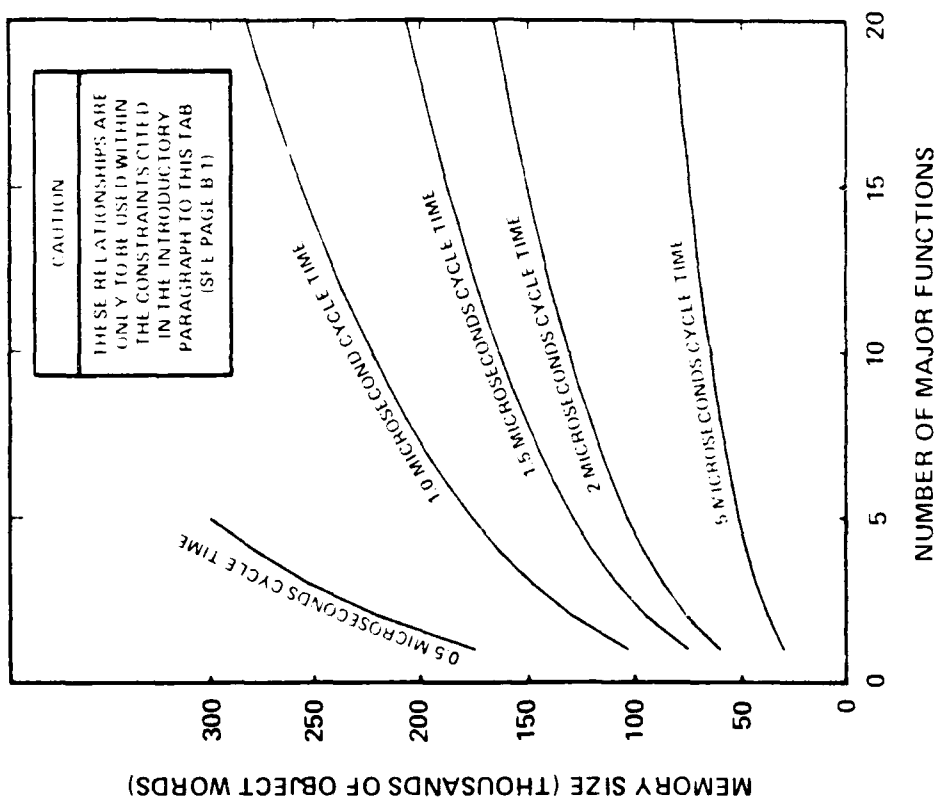
<u>Tab</u>	<u>Page</u>
B.5.1 8 bits/word.	B-35
B.5.2 12 bits/word.	B-36
B.5.3 16 bits/word.	B-37
B.5.4 24 bits/word.	B-38
B.5.5 32 bits/word.	B-39
B.5.6 64 bits/word.	B-40



TAB B.5.1 MEMORY SIZE VS CYCLE TIME AND NUMBER OF FUNCTIONS
(8 BITS/WORD)



TAB B.5.2 MEMORY SIZE VS CYCLE TIME AND NUMBER OF FUNCTIONS
(12 BITS/WORD)



TAB B.5.3 MEMORY SIZE VS CYCLE TIME AND NUMBER OF FUNCTIONS
(16 BITS/WORD)

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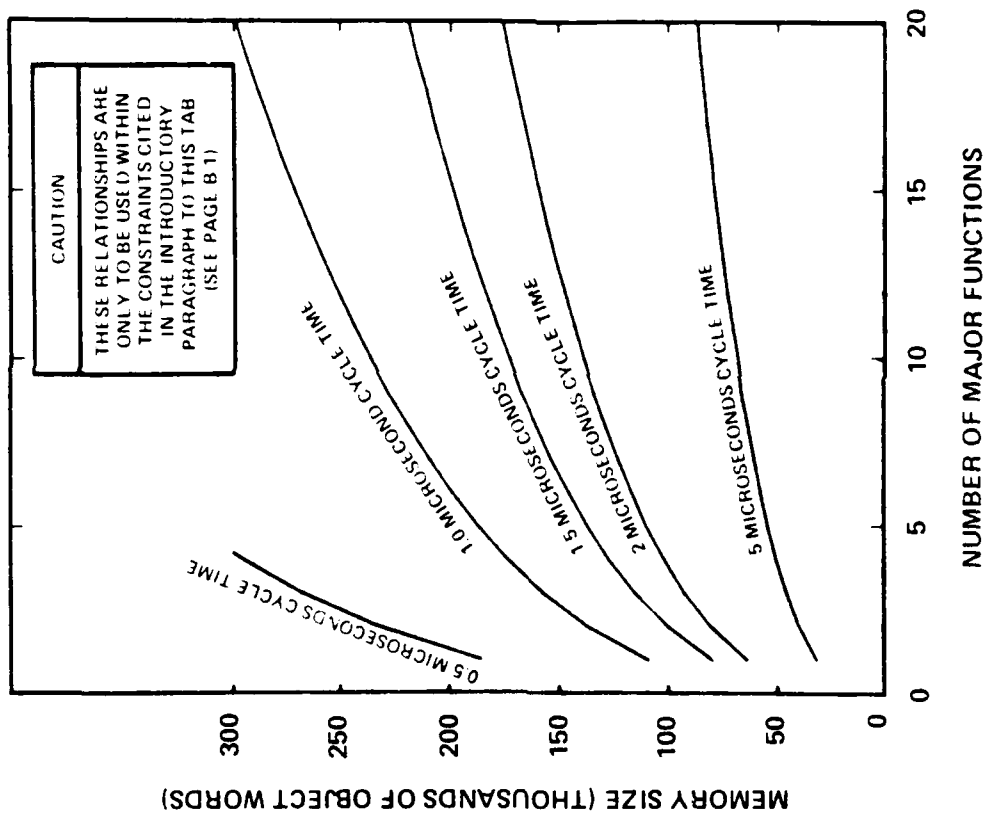
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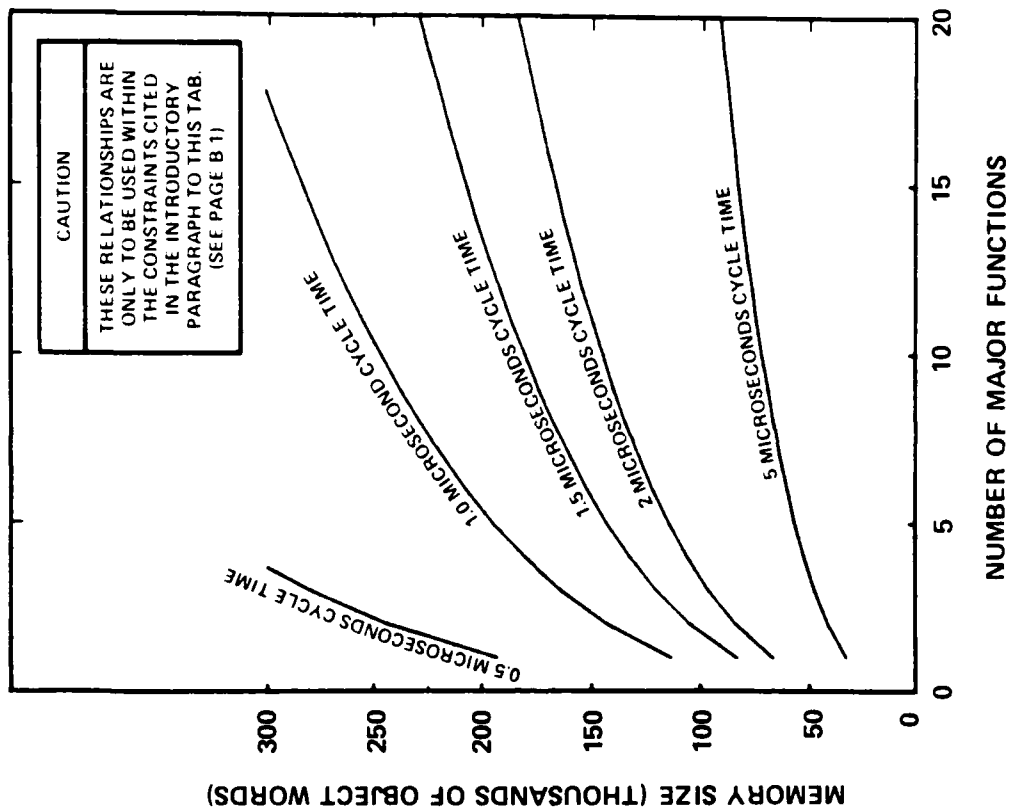
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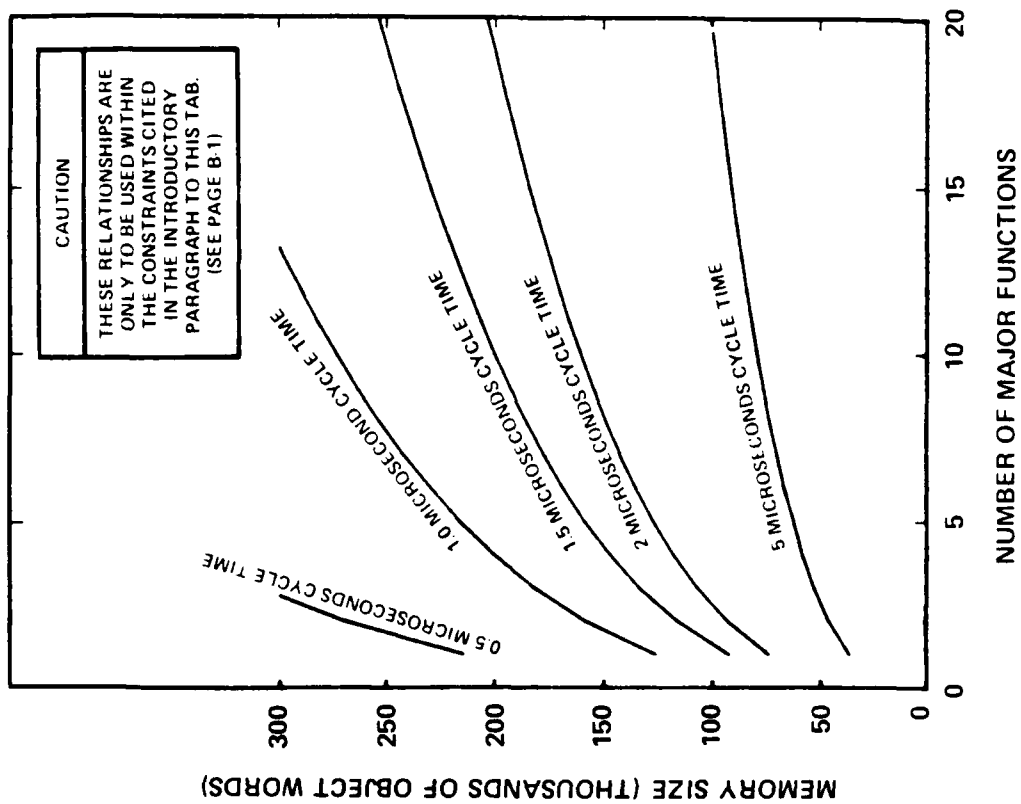
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TAB B.5.4 MEMORY SIZE VS CYCLE TIME AND NUMBER OF FUNCTIONS
(24 BITS/WORD)



**TAB B.5.5 MEMORY SIZE VS CYCLE TIME AND NUMBER OF FUNCTIONS
(32 BITS/WORD)**



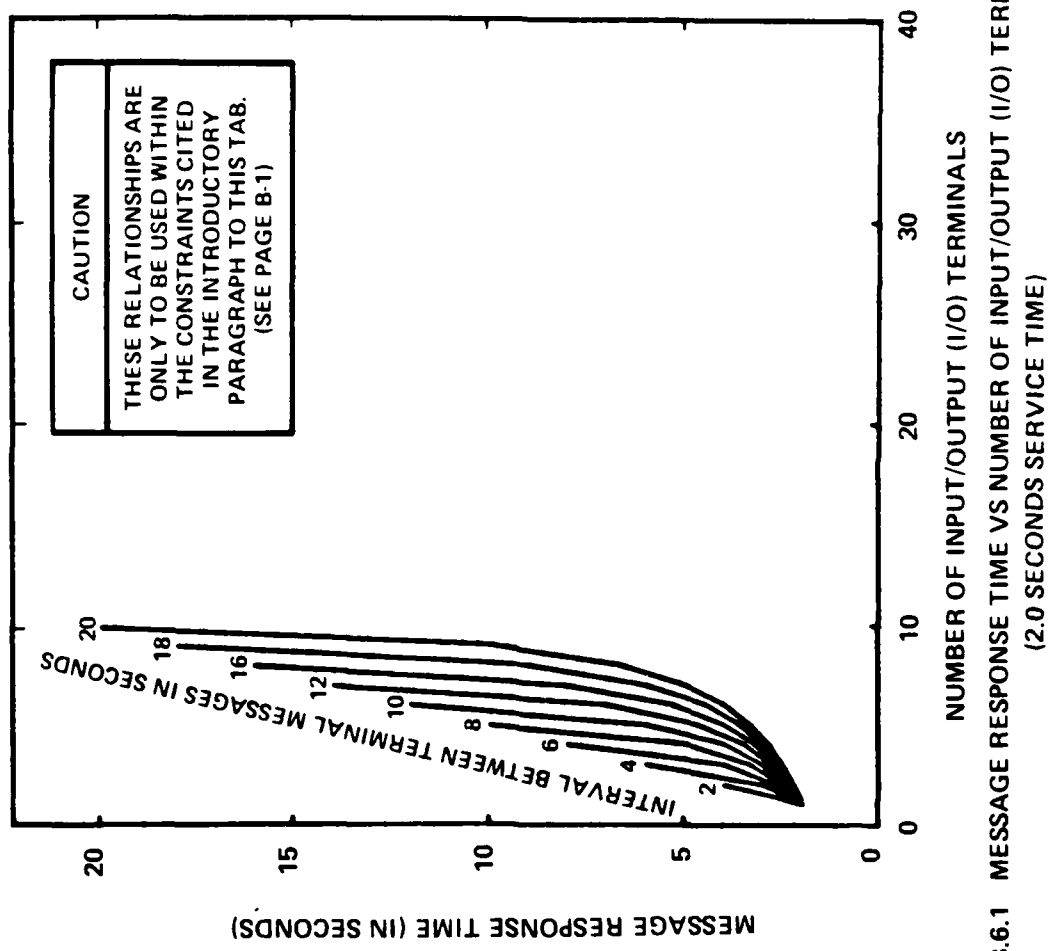
TAB B.5.6 MEMORY SIZE VS CYCLE TIME AND NUMBER OF FUNCTIONS
(64 BITS/WORD)

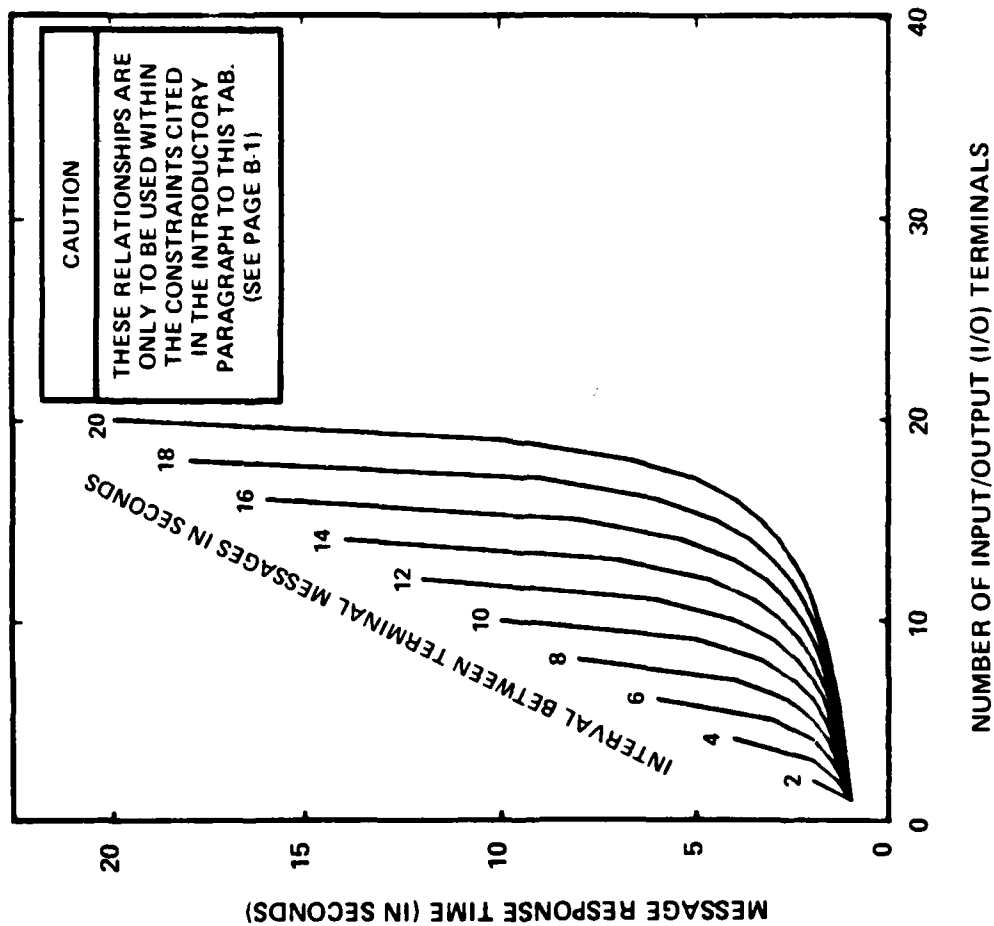
TAB B.6 MESSAGE RESPONSE TIME VS. NUMBER OF
INPUT/OUTPUT (I/O) TERMINALS

The relationships illustrated in this set of Tabs, B.6.1 through B.6.3, were developed through the application of queuing theory. These curves illustrate the relationships among the number of I/O terminals, the probable response time depending on CPU service time, and the interval between terminal messages. It should be noted that as the service time becomes less, the easier it is to service more terminals. The curves also show that the longer the time between terminal messages, the easier it is to accommodate more terminals. The limiting factor is approximated by dividing the interval between terminal messages by the service time to get the limiting number of I/O terminals that can reasonably be serviced.

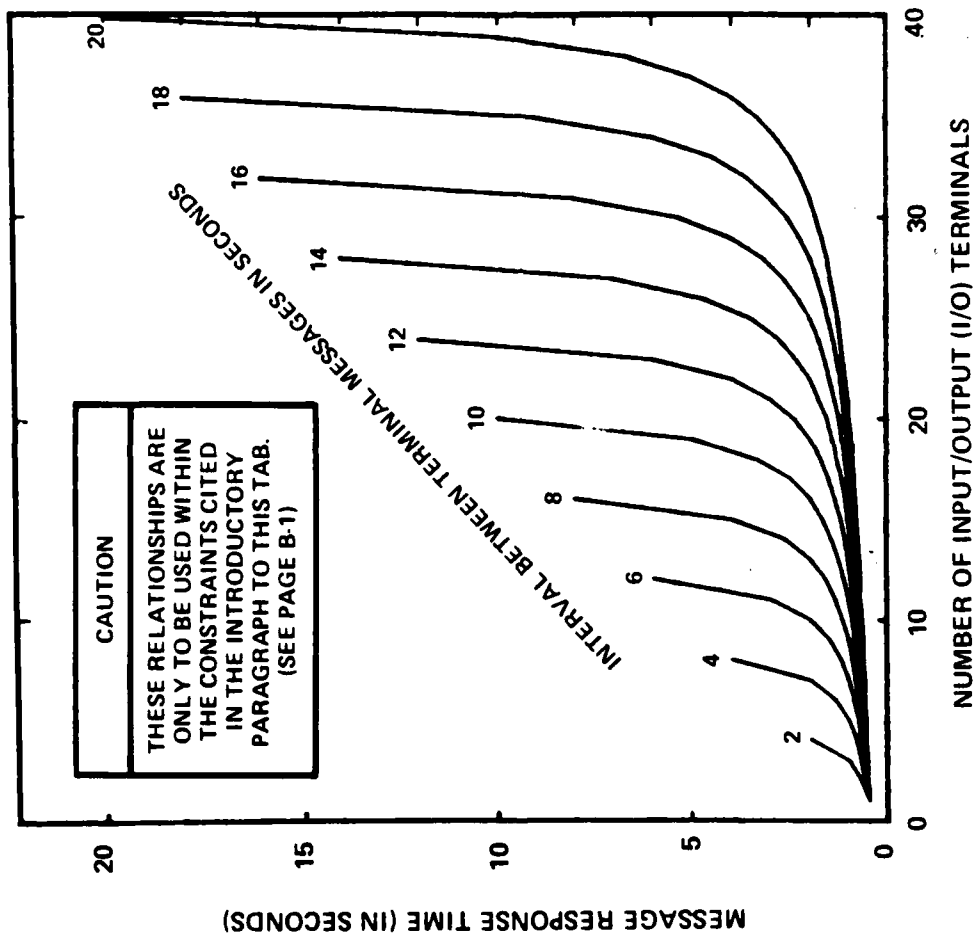
MESSAGE RESPONSE TIME VS. NUMBER
OF INPUT/OUTPUT (I/O) TERMINALS

<u>Tab</u>		<u>Page</u>
B.6.1	2.0 seconds service time.	B-42
B.6.2	1.0 second service time	B-43
B.6.3	0.5 second service time	B-44





TAB B.6.2 MESSAGE RESPONSE TIME VS NUMBER OF INPUT/OUTPUT (I/O) TERMINALS
(1.0 SECOND SERVICE TIME)



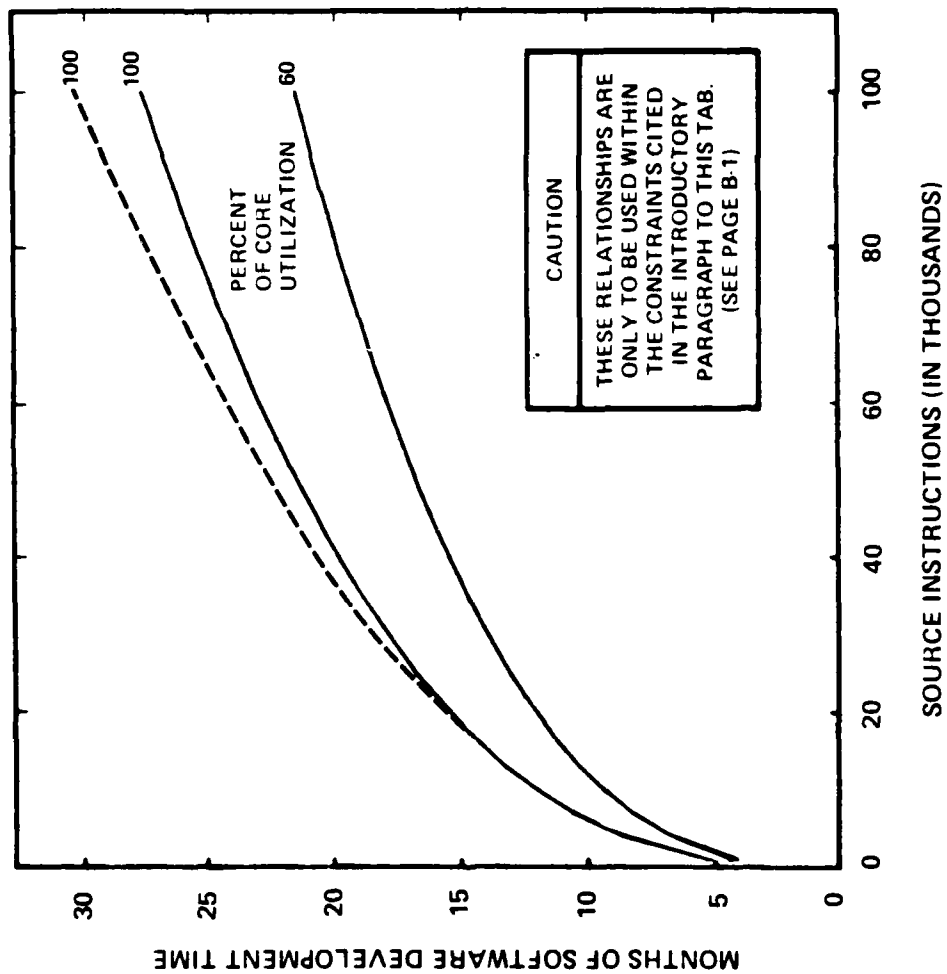
**TAB B.6.3 MESSAGE RESPONSE TIME VS NUMBER OF INPUT/OUTPUT (I/O) TERMINALS
(0.5 SECOND SERVICE TIME)**

TAB B.7 MONTHS OF SOFTWARE DEVELOPMENT TIME VS.
CORE UTILIZATION

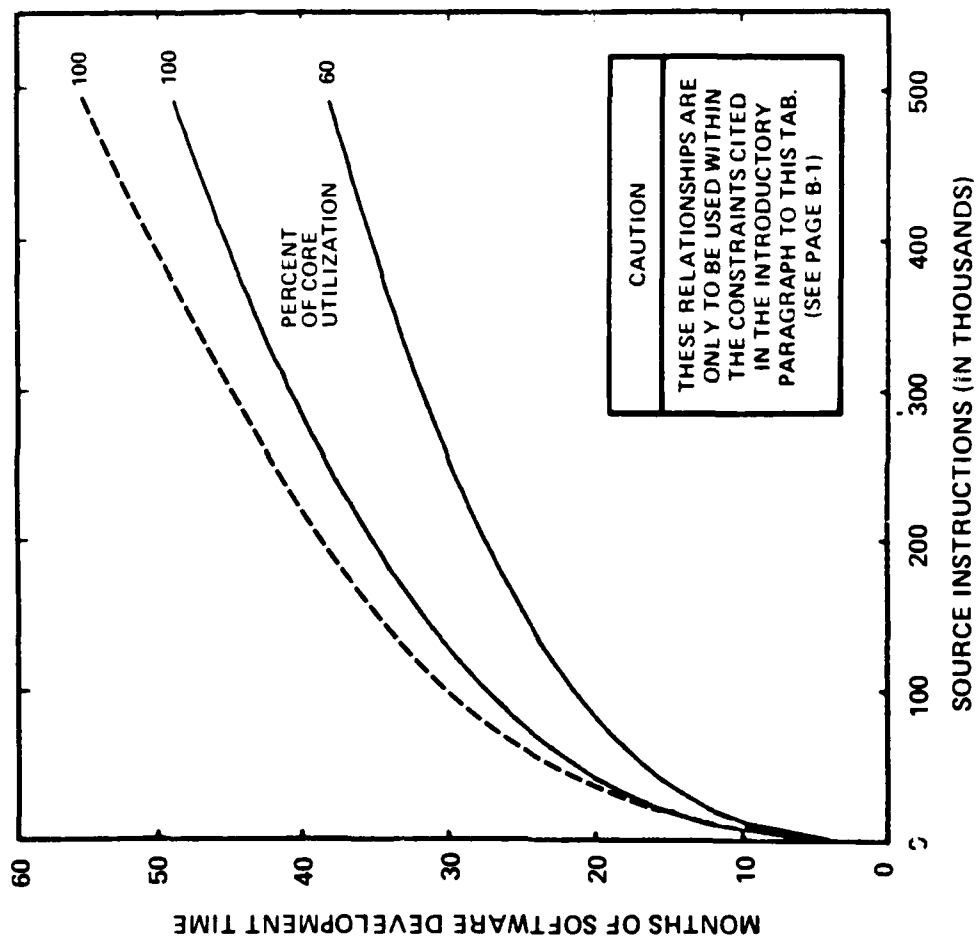
The relationships illustrated in this set of Tabs, B.7.1 and B.7.2, were developed through the application of the algorithm (Equation 5) discussed in Tab B, Section 1.1.3. These curves illustrate the relationship between the number of lines of source instructions that are to be developed, and the number of months required to develop them, considering the impact of core utilization. The use of the algorithm (Equation 5) indicates that the development time increases as the core utilization increases (see Tabs B.7.1 and B.7.2). In reality, the increase in the development time should increase more exponentially as illustrated by the suggested curve (dotted line) in Tabs B.7.1 and B.7.2. (Also see discussion on hypothetical algorithm in Tab B, Section 1.1.3.) It is suggested that for less than 60% utilization, the 60% curve be used.

MONTHS OF SOFTWARE DEVELOPMENT
TIME VS. CORE UTILIZATION

<u>Tab</u>		<u>Page</u>
B.7.1	Up to 100,000 source instructions	B-46
B.7.2	Up to 500,000 source instructions	B-47



TAB B.7.1 MONTHS OF SOFTWARE DEVELOPMENT TIME VS CORE UTILIZATION
(UP TO 100,000 SOURCE INSTRUCTIONS)



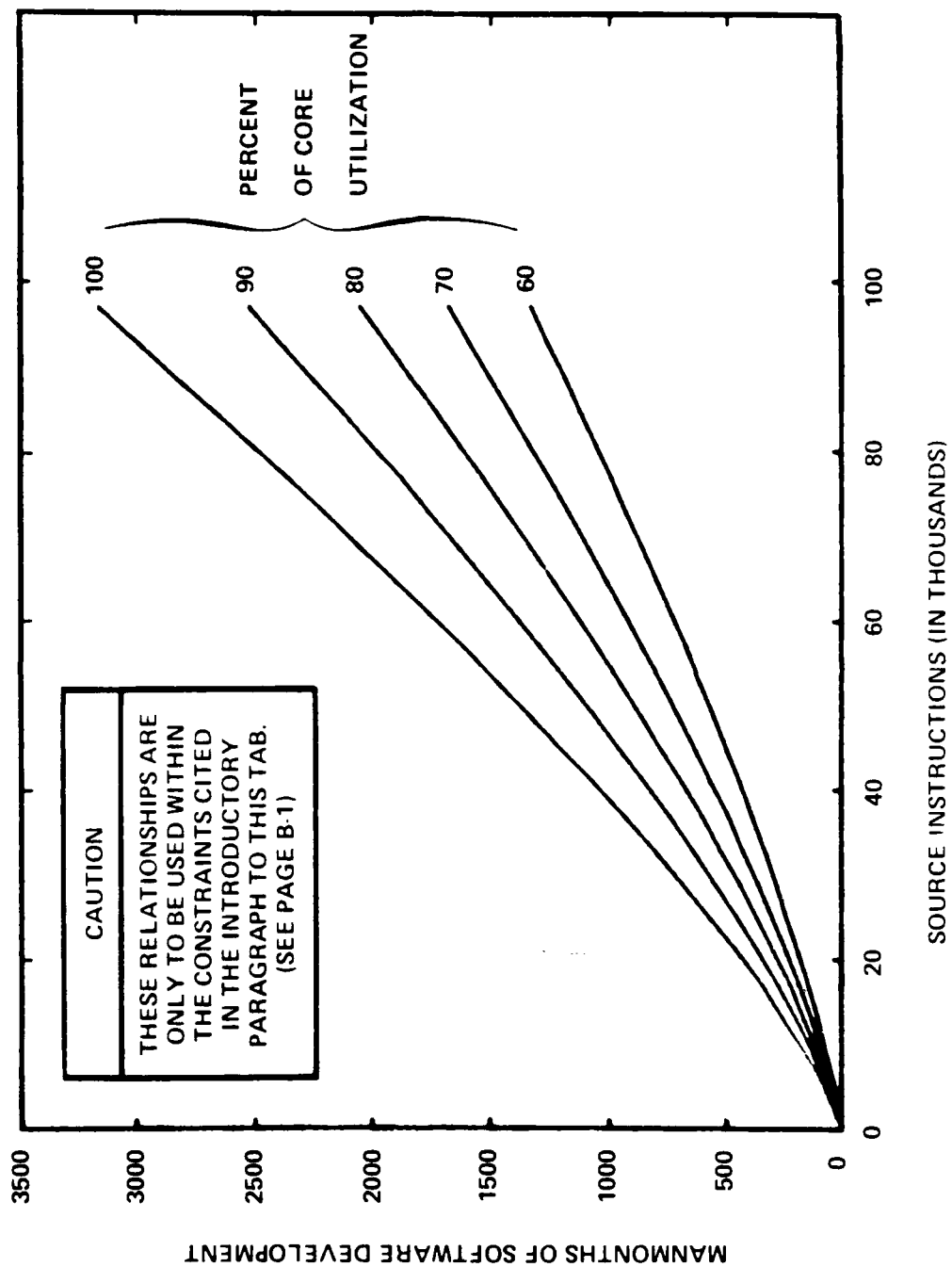
**TAB B.7.2 MONTHS OF SOFTWARE DEVELOPMENT TIME VS CORE UTILIZATION
(UP TO 500,000 SOURCE INSTRUCTIONS)**

TAB B.8 MANMONTHS OF SOFTWARE DEVELOPMENT TIME
VS. CORE UTILIZATION

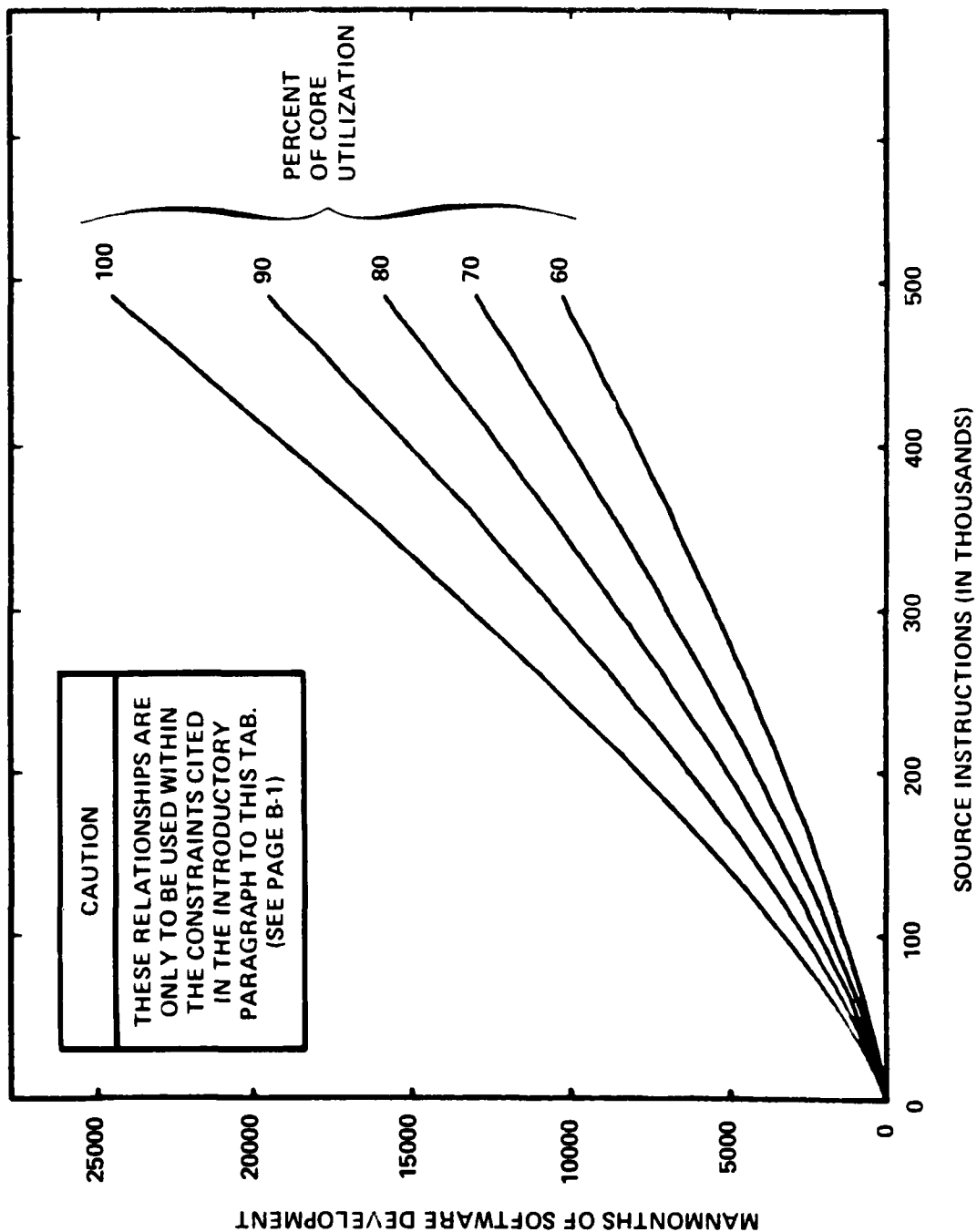
The relationships illustrated in this set of Tabs, B.8.1 and B.8.2, were developed through the application of the algorithm (Equation 7) discussed in Tab B, Section 1.1.4. These curves show the relationships between the number of lines of source instructions that are to be developed, and the number of manmonths of effort required to develop them considering the impact of core utilization. Note that as core utilization increases from 60% to 100% the manmonths of effort increases. It is suggested that for less than 60% utilization, the 60% curve be used.

MANMONTHS OF SOFTWARE DEVELOPMENT TIME
VS. CORE UTILIZATION

<u>Tab</u>		<u>Page</u>
B.8.1	Up to 100,000 source instructions	B-49
B.8.2	Up to 500,000 source instructions	B-50



TAB B.8.1 MANMONTHS OF SOFTWARE DEVELOPMENT TIME VS CORE UTILIZATION
(UP TO 100,000 SOURCE INSTRUCTIONS)



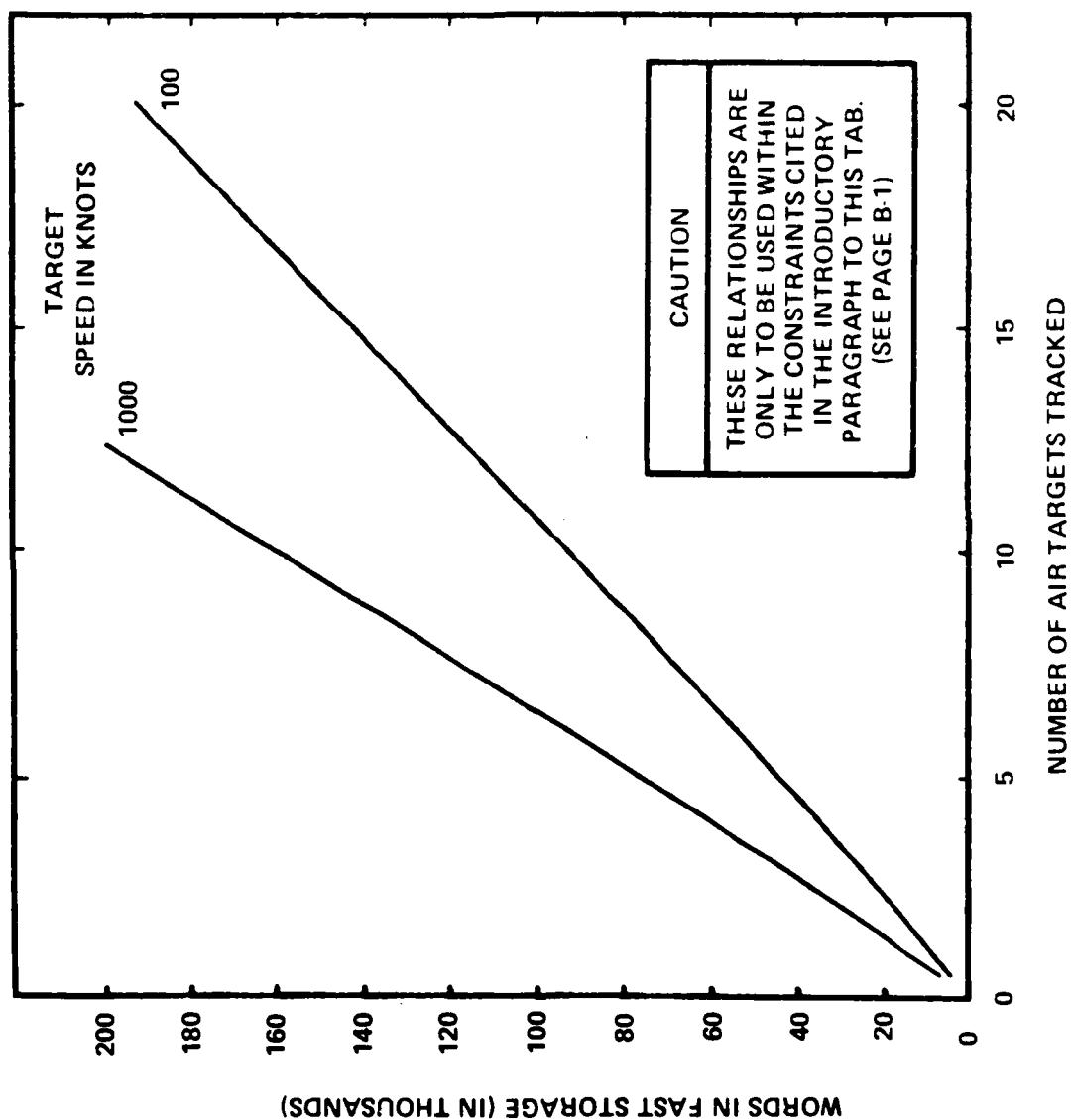
**TAB B.8.2 MANMONTHS OF SOFTWARE DEVELOPMENT TIME VS CORE UTILIZATION
(UP TO 500,000 SOURCE INSTRUCTIONS)**

TAB B.9 FAST STORAGE CAPACITY VS. NUMBER OF
AIR TARGETS TRACKED

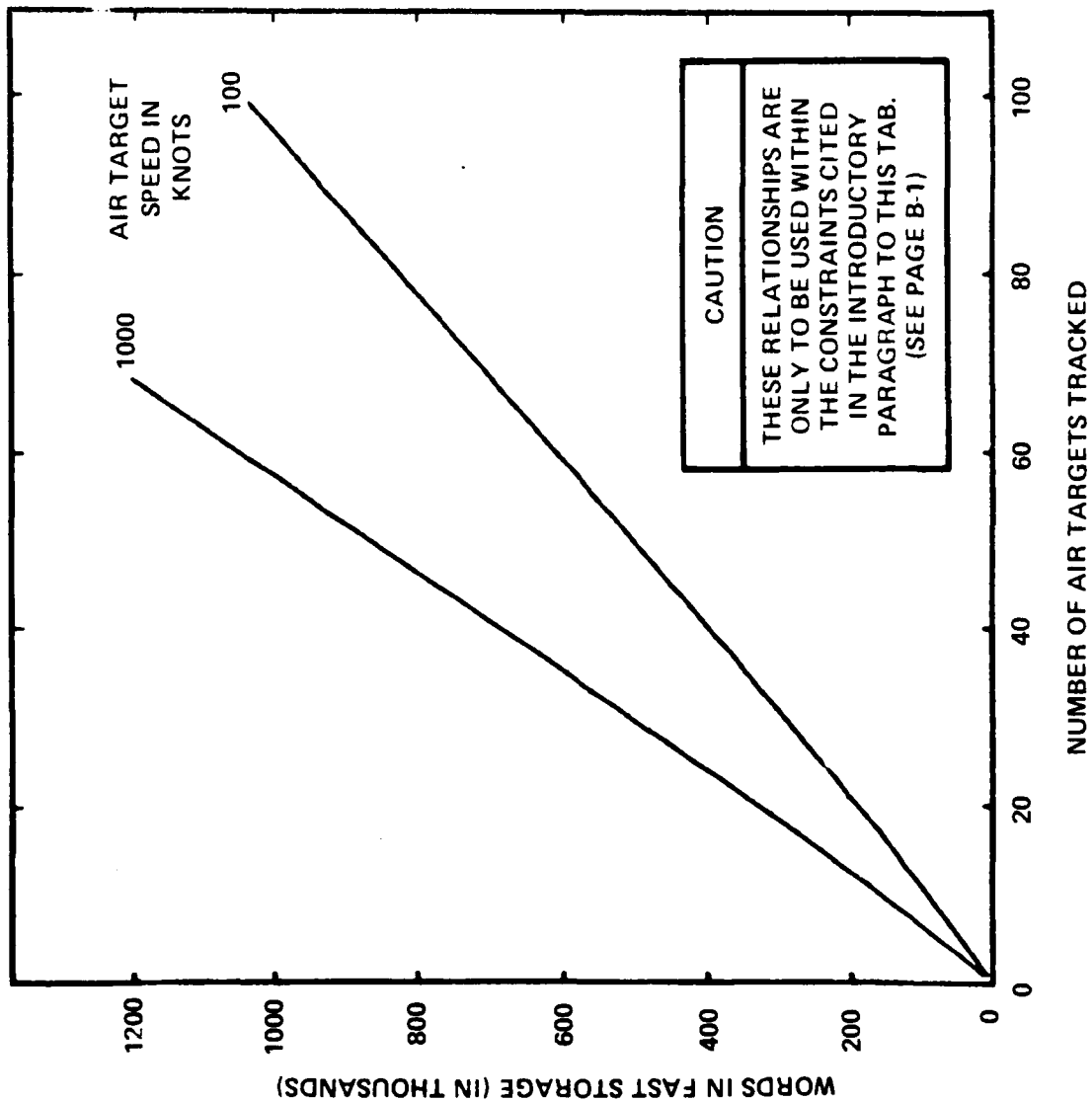
The relationships illustrated in this set of Tabs, B.9.1 and B.9.2, were developed through the application of the algorithms (Equations 8 and 9) discussed in Tab B, Section 1.1.5. These curves show the impact on fast storage capacity as the number of targets tracked and approach speed increase. As the speed of the target increases, or as the number of targets tracked increases, the number of words of fast storage increases. Fast storage is defined in Tab B, Section 1.1.5.

FAST STORAGE CAPACITY VS. NUMBER
OF AIR TARGETS TRACKED

<u>Tab</u>	<u>Page</u>
B.9.1 Up to 20 targets.	B-52
B.9.2 Up to 100 targets	B-53



TAB B.9.1 FAST STORAGE CAPACITY VS NUMBER OF AIR TARGETS TRACKED (UP TO 20 TARGETS)



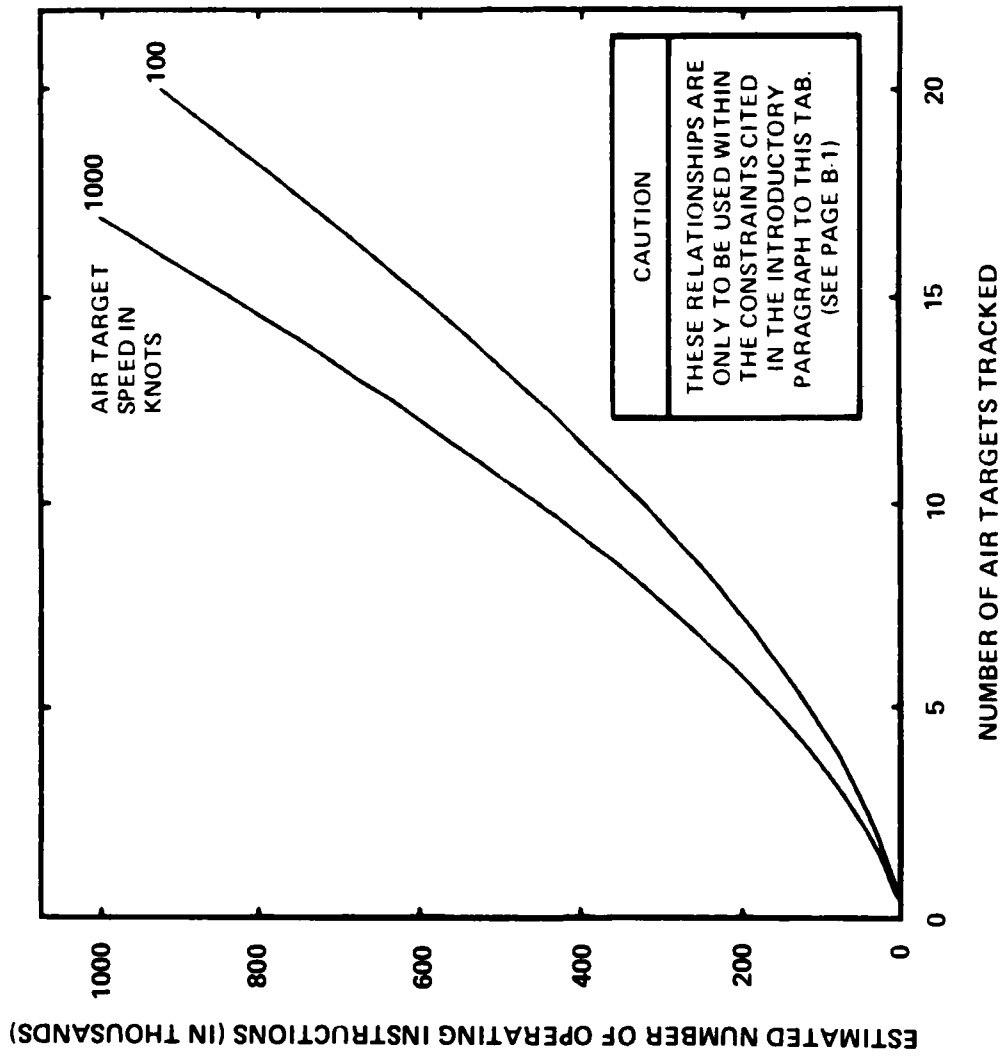
TAB B.9.2 FAST STORAGE CAPACITY VS NUMBER OF AIR TARGETS TRACKED (UP TO 100 TARGETS)

TAB B.10 NUMBER OF INSTRUCTIONS VS. NUMBER OF
AIR TARGETS TRACKED

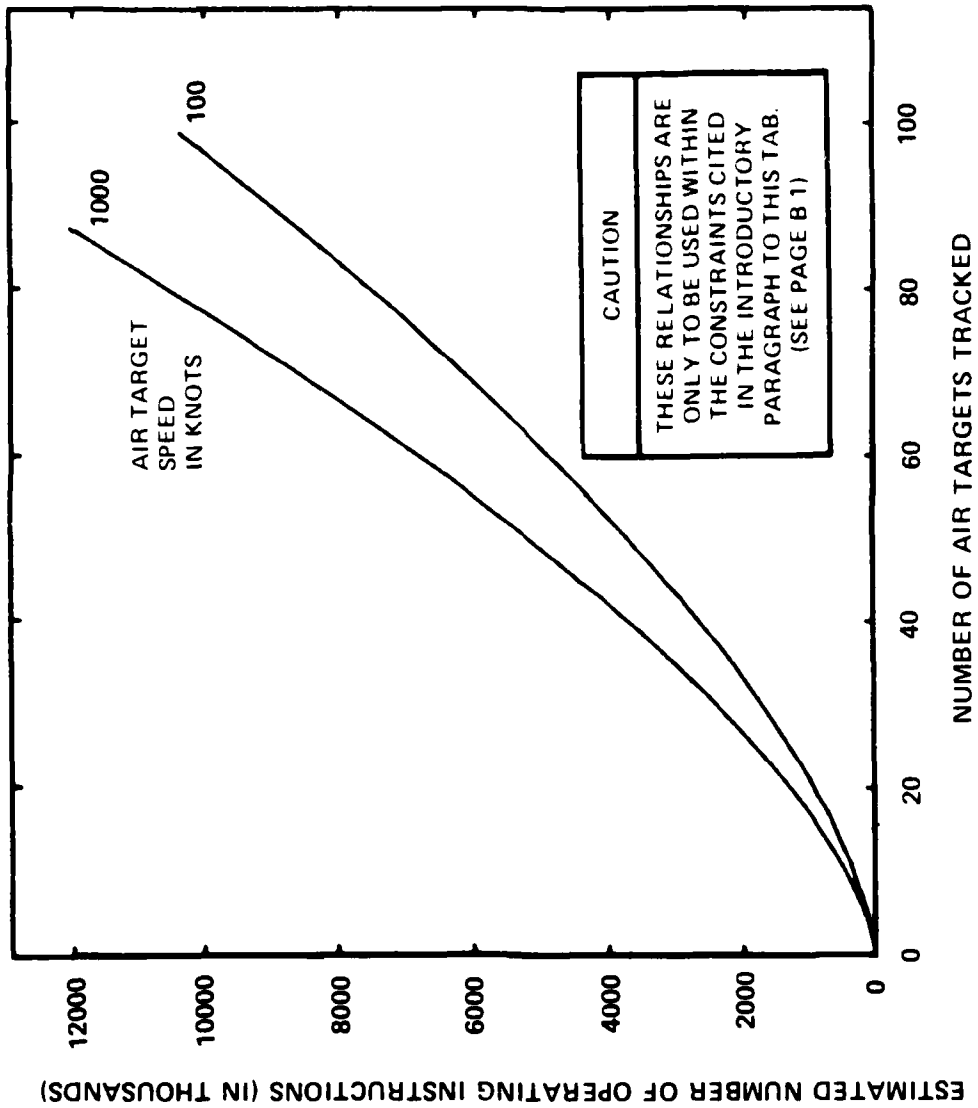
The relationships illustrated in this set of Tabs, B.10.1 and B.10.2, were developed through the application of the algorithms (Equations 10 and 11) discussed in Tab B, Section 1.1.5. These curves show the impact on total operating instructions as the number of targets tracked.

NUMBER OF INSTRUCTIONS VS. NUMBER
OF AIR TARGETS TRACKED

<u>Tab</u>		<u>Page</u>
B.10.1	Up to 20 targets.	B-55
B.10.2	Up to 100 targets	B-56



TAB B.10.1 NUMBER OF INSTRUCTIONS VS NUMBER OF AIR TARGETS TRACKED (UP TO 20 TARGETS)

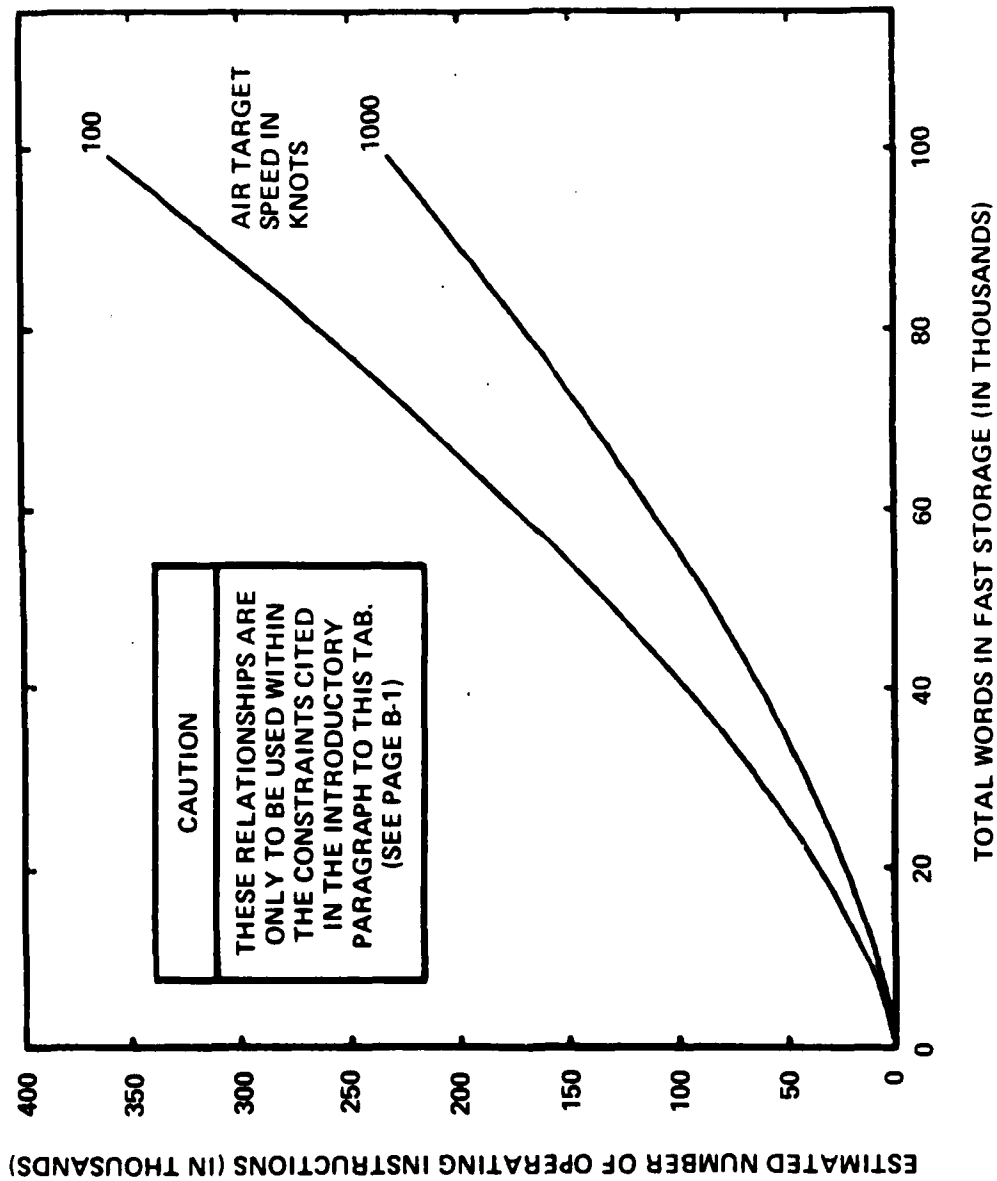


TAB B.10.2 NUMBER OF INSTRUCTIONS VS NUMBER OF AIR TARGETS TRACKED
(UP TO 100 TARGETS)

TAB B.11 NUMBER OF INSTRUCTIONS VS. FAST STORAGE
CAPACITY/AIR TARGET SPEED

The relationships illustrated in this Tab, B.11.1, were developed through the application of the algorithms (Equations 8 through 11) discussed in Tab B, Section 1.1.5. These curves show the relationships between the number of operating instructions to the number of words in fast storage and the speeds of the targets tracked. The curves illustrate that for larger size operational software, a greater proportion of the total operating software is required to be resident in fast storage. Fast storage is defined in Tab B, Section 1.1.5.

<u>Tab</u>	<u>Page</u>
B.11.1	NUMBER OF INSTRUCTIONS VS. FAST STORAGE CAPACITY/AIR TARGET SPEED . . B-58



TAB B.11.1 NUMBER OF INSTRUCTIONS VS FAST STORAGE CAPACITY AND AIR TARGET SPEED

TAB C
EXAMPLES OF THE APPLICATION OF PROCEDURES

CASE 1 - Example of the Application of Procedures to an Initial Sizing and Timing Study	C-3
CASE 2 - Example of the Application of Procedures to Developmental Monitoring	C-11

CASE 1 - EXAMPLE OF THE APPLICATION OF PROCEDURES TO AN INITIAL SIZING AND TIMING STUDY

A. INTRODUCTION

This is an example of the application of the procedures discussed in Volume I of this handbook. The example illustrates a number of the problems that can be encountered in conducting a sizing and timing study, particularly an initial study. It is recommended that the reader refer to the handbook sections in Volume I and the Tabs of both volumes cited throughout this example. This will provide a better understanding of the step-by-step procedures being taken.

B. BACKGROUND

At the recently formed Program Office for FAR VIEW, Lt. Sutter has been requested to conduct an initial computer system sizing and timing study. Having reported a couple of weeks earlier, and this being her first sizing and timing study effort, Lt. Sutter recalled her predecessor, Captain Reeves, mentioning that the Handbook of Procedures for Estimating Computer System Sizing and Timing Parameters should prove of value in conducting a study. Lt. Sutter obtained the FAR VIEW documentation from her files and the handbook from her bookshelf, and noted from a program schedule that FAR VIEW was near the end of the Conceptual Phase of its acquisition. Seated at her desk, she quickly read the text and the introduction sections to the various tabs, and also scanned the rest of the contents of both volumes. With that, Lt. Sutter turned to Section 5 of the handbook and began to follow the procedural steps for an initial sizing and timing study (see Section 5.2).

C. DETERMINING THE OBJECTIVES

1. Of the seven suggested objectives listed in Section 5.2.1, Lt. Sutter knew that her task was to conduct an initial estimation of the sizing and timing parameters of the computer system in the FAR VIEW project. The

parameters that were considered the most vital to the performance of the system were the main and bulk storage capacities and the terminal response times; more specifically:

- The main storage had to be large enough to handle all core resident programs and data requirements, plus have a 25 percent reserve capacity for future growth upon delivery.
- The bulk storage had to be large enough to handle all programs and data requirements of the system.
- The response time at the terminals has to meet user established requirements.

2. As for the resources available to conduct the study, Lt. Sutter knew she was the only one tasked to do the study and that time was of the essence.

3. At this point in time, Lt. Sutter assumed that she would use only terms with standard definitions (see glossary in Volume I of handbook), and surmised that in the event unusual terms were required, she would ensure that definitions were provided in the study documentation.

4. Considering that the FAR VIEW project was near the end of the Conceptual Phase, and having previously reviewed the project documentation she had in file, Lt. Sutter estimated that the anticipated degree of accuracy of the final study results could be in error by at least 100 percent.

5. Although the study was for the internal use of the Program Office, Lt. Sutter planned to include ESD/TOI in the distribution so that a copy of the report would be retained in their sizing and timing study repository.

D. DEFINE SYSTEM BOUNDARIES AND WORKLOADS

1. In an attempt to define the system's boundaries and workloads (see Section 5.2.2), Lt. Sutter reviewed the system documentation that was in

her files; a Statement of Work (SOW) for FAR VIEW, a System Performance Specification, and a Data Requirements Package. In the SOW, Lt. Sitter noted the following as having possible impact on the system's sizing and timing parameters:

- The contractor was to perform a functional analysis using the system operational concepts.
- Each subsystem was to be allocated a set of performance parameters, and the contractor was to conduct an engineering analysis of the FAR VIEW System Specification and prepare the Configuration Identification documentation.
- The contractor was also to conduct tradeoff studies in an effort to optimize the performance parameters.
- Software development by the contractor was to be performed according to modern programming techniques.
- The software language prescribed for FAR VIEW was to be JOVIAL; however, exceptions could be made for highly used algorithms.
- The contractor was to propose off-the-shelf computer system equipment to the maximum extent possible.

The System Performance Specification contained the following information of value:

- FAR VIEW was defined as a single unit, new fixed phased array warning system, that was to be used to detect ICBMs in a designated sector of air space. The selection of the location for the system facility was in its final stages of approval.
- The system would consist of a radar subsystem, a data processing subsystem, a communications subsystem, and a facilities subsystem.
- FAR VIEW must perform the following functions in order to accomplish and support its primary mission of detecting incoming ICBMs, and predicting their time and point of impact:
 - surveillance,
 - tracking,

- discrimination,
 - reporting,
 - radar scheduling and control,
 - performance monitoring,
 - displays and controls,
 - simulation, exercises and tests,
 - data recording and reduction,
 - maintenance and diagnostics,
 - mission planning, and
 - special search and track requests,
- The maximum of projected ICBMs in the designated sector of air space was estimated to be 80.
 - Four identical display consoles were to be provided. Each console would normally perform one of the following functions:
 - systems operations, monitoring and control,
 - missile warning operations,
 - training (also as back up for other consoles), and
 - maintenance monitoring and control.

Each console was to have the capability to handle operators messages and provide both tabular and graphic displays.
 - Detailed console display requirements were delineated in the System Performance Specification.
 - Software programs were to include the following as a minimum:
 - executive control program that included 9 designated functions,
 - functional and application programs that contained monitoring and calibration software must be on-line with the operational programs,
 - diagnostic programs that must be disc resident,
 - simulation programs must be on-line with the operational, monitoring, and calibration programs, and
 - support programs for the above must be provided.
 - Tactical messages were delineated in the System Performance Specification.

- Response time from missile acquisition to display of missile warning message on console was not to exceed the time required for the signal processing function plus the minimum data processing time.
- The time required for an Impact and Time (I&T) message to be displayed on a console was not to exceed the time required for the signal processing function and necessary calculations to provide the data in the I&T message.

The Data Requirements Package did not provide any sizing and timing data.

The only definition of a workload was the identification of the maximum number of projected ICBMs (80 total) that would require tracking, monitoring and analysis at any one period of time, plus the times required for console displayed data.

2. Lt. Sutter drew a block diagram of the computer system as she envisioned it, and also made a list of software characteristics based on the information she had obtained above. She had not identified any information in the project documentation regarding software sizing.

3. At this point, Lt. Sutter wondered aloud whether she would be able to achieve the study objectives; however, she considered the next step in the sizing and timing procedures and decided to continue with her initially established study objectives.

E. ESTABLISH CANDIDATE TECHNIQUES (see Section 5.2.3)

Realizing that she did not have too many details regarding the FAR VIEW system, Lt. Sutter reviewed the illustration of sizing and timing techniques in Figure 6, and the discussion in Tab A of Volume I of the handbook. She came to the conclusion that, due to the lack of system sizing and timing data, she should try using analogies and possibly some analytical techniques if enough possible parameters or data could be obtained. She also made a note of the confidence level of the candidate techniques.

F. IDENTIFY AND QUALIFY DATA SOURCES (see Section 5.2.4)

Lt. Sutter reviewed Tab A, Volume II of the handbook and a report of ESD C³ system acquisitions and noted that there were two other phased-array radar systems that were to perform functions similar to FAR VIEW, though the hardware of the two computer systems was somewhat different. In addition, Lt. Sutter contacted other staff members of FAR VIEW Program Office and obtained a copy of the contractor's proposal that provided a listing of the hardware he proposed and his estimate of software size.

G. PREPARE DETAILED STUDY APPROACH

Following the guidance in Section 5.2.5, Lt. Sutter prepared a detailed study plan. She defined the FAR VIEW system boundaries based on the information she had obtained from the System Performance Specification and the contractor's proposal (see Sections D.1 and F above). Listing constraints and assumptions, Lt. Sutter noted under constraints that FAR VIEW's workloads could not be defined and that timing data for FAR VIEW did not exist except for a few parameters cited in the System Performance Specification. As for assumptions, Lt. Sutter noted that two other phased-array radar systems performed similar functions, therefore, correlations might be made between the functions, software and data sizes, hardware requirements, and maybe even workloads. Also, she made the assumption that the reserve memory capacity of the two systems was between 20-25 percent and that the data bases were approximately the same.

H. CONDUCT, CORRELATE AND ANALYZE STUDY (see Sections 5.2.5 through 5.2.8)

In order to compare similar equipments and functions, Lt. Sutter developed a table of data regarding the three systems. The table below illustrates some of the highlights of Lt. Sutter's comparison table that went into considerable detail, such as descriptions of each software and system function, etc.

	FAR VIEW	SYSTEM-A	SYSTEM-B
<ul style="list-style-type: none"> • System • Main Memory • Cycle Time • Tape Drives • Disc Units • Displays 	1-CDC CYBER 174-12 (proposed) 198K-60 bit/words 0.4 microsec 3 ea 2 ea 4 CDC 777	1-CDC CYBER 74-18 120K-60 bit/words 1.0 microsec 2 ea 2 ea 5 CDC 243-2	1-UNIVAC 1110 110K-26 bit/words 0.52 microsec 4 ea 2 ea 3 UNIVAC
<ul style="list-style-type: none"> • Software Size (Estimate) • Breakdown by S/W functions • Source to Object Code Conversion Ratio 	200K deliverable source statements 12 1:2	400K object statements Not available 1:2	440 K object statements Not available 1:3
<ul style="list-style-type: none"> • Data Size (Estimate) 	Not available (See assumptions)	Not available (See assumptions)	Not available (See assumptions)
<ul style="list-style-type: none"> • System Functions • Maximum Number Targets 	12 80	14 Not available	9 Not available

Based on Lt. Sutter's analysis of her detailed comparison table, she concluded that the proposed computer system for FAR VIEW appeared adequate to perform the functions required, including those of the operating system; however, she could not quantify the bulk storage available nor the estimated terminal response times. By using Equation 1 cited in Tab B, Volume II of the handbook, Lt. Sutter calculated that the required capacity for both programs and data in the main memory could be approximately 135 thousand object words, assuming that: the primary application was signal processing; twelve major functions were to be performed by the software; the word size was a 60 bit-word; and the cycle time was 0.4 microseconds. Considering another 68 thousand object words

for reserve capacity (using Equation 1 cited in Section 6.2, Volume I of the handbook this reserve capacity equated to 33 percent of the total available memory), Lt. Sutter noted that the total approximately equalled the main memory capacity of the proposed computer. It should be noted that Lt. Sutter correctly identified the primary application of the ECS as signal processing and used the constant for signal processing in the equation. Had she considered the application as command and control, and used that constant in the equation, the solution to the calculation would have indicated that approximately four times more memory capacity would be required. This larger capacity estimate would not have been consistent with her analogy comparison table data, and would hopefully have encouraged LT. Sutter to evaluate the disparity. The point that Lt. Sutter and the readers should remember in estimating efforts is to consider as many data points as possible and the level of confidence of each data point.

I. PREPARE THE STUDY REPORT (see Section 5.2.9)

Lt. Sutter structured her report as suggested by the handbook. In the report, she emphasized that initial estimates near the end of the Conceptual Phase could be in error by 100 percent, and cited the paucity of sizing and timing data, especially workloads. She discussed the comparison of the three computer systems and concluded that the proposed system for FAR VIEW appeared reasonable; therefore, it could be assumed that bulk storage requirements would be met. Acknowledging the large error possibility, the main memory capacity also appeared reasonable, though she also recommended close monitoring of the software development, as well as any possible growth in user requirements for more data. She also commented on the fact that without the workloads, she was unable to estimate response times. In completing the report, Lt. Sutter included a recommendation that the study report be brought to the attention of the contractor and the user organization. As soon as the report was prepared, Lt. Sutter submitted it and made a mental note to discuss the report with ESD/TOI.

CASE 2 - EXAMPLE OF THE APPLICATION OF PROCEDURES
TO DEVELOPMENTAL MONITORING

A. BACKGROUND

The SKY WATCH project, the development of radar warning system, is in the sixteenth month of Full-Scale Development (FSD). The FSD phase is scheduled for 36 months and, until the last month, appears to have been going well, even though the initial Preliminary Design Review (PDR) and the Critical Design Reviews (CDR) slipped by about 3 months each. The CDR for CPCI No. 1, RDRSWTC (radar switching), was conducted and resulted in the following breakdown in terms of lines of code:

<u>CPCI</u>	<u># CPCs</u>	<u># MODULES</u>	<u>ESTIMATED SOURCE CODE</u>
RDRSWTC	15	56	12,000

This breakdown has changed since the original submission of the Computer Program Development Plan (CPDP). The original and revised estimates for CPCI RDRSWTC are as follows:

		ORIGINAL	REVISED
ESTIMATED NUMBER OF INSTRUCTIONS	EXISTING CODE	6,000F*	4,000F
	CONVERSION CODE	2,000F	2,250F
	NEW CODE	2,000F	5,750F
	TOTAL CODE	10,000F	12,000F
ESTIMATED EFFORT IN MANMONTHS	ANALYSIS	0	10**
	DESIGN	18	20**
	CODE AND CHECKOUTS	12	12
	TEST AND INTEGRATION	24	18
	TOTAL THROUGH INTEGRATION	60	60

*F Denotes FORTRAN

**Actual Expenditures

Discussions with the contractor have resulted in less than satisfactory answers regarding the mix of code types within the 12,000 lines of source code. The question has been raised on the breakdown of executable, nonexecutable, comment, and data definition code. The definition of this breakdown is important in the ultimate memory requirement in terms of words of storage, and also in the resources required to develop, test and integrate the CPCI.

The Sizing and Timing Officer (S&TO) has been tasked with providing developmental monitoring reports on the progress of the developed computer programs. The current emphasis is on the verification of the estimated size of the programs and whether the estimated resources and development time are sufficient. In addressing CPCI RDRSWTC for month 16, the S&TO proceeded in accordance with paragraph B. below.

B. PROCEDURE APPLICATION (reference Section 5.4, Volume I)

1. Prepare Prediction Set

The prediction set for the value of the total source code for CPCI RDRSWTC (one of several sets), was prepared and is shown in Figure C-1. This shows that, as of the completion of the month 15 monitoring, the beginning prediction value of source lines of code was 12,000, and that the estimated value after analysis was 13,000 lines. This value of 13,000 is not the value that will be the "LAST VALUE" in month 17, and the estimate to be done herein will be the "PREDICTED VALUE AS OF THIS DATE" for month 17. Items 6, 7, and 8 will be entered upon completion of this month's (month 16) estimate.

2. Verify Analysis Techniques

There were two assumptions that have been used in the development of size and resource estimates. These two assumptions must be verified as the coding and testing progresses. First, there is the set of relationships dealing with the conversion from FORTRAN source statements to words of core. It has been stated that, based on one object instruction per

PREDICTION SET Month <u>16</u> PROGRAM: <u>SKY WATCH</u> DATE: <u>22 Feb. 1980</u> EVALUATOR: <u>Lt. R. B. Jones, USAF</u>		
1	KEY VALUE (and Parameters)	Total Source Code for CPCI (RDRSWTC)
2	LAST VALUE Prediction Set Month: <u>15</u> of: <u>25 Jan. 1980</u>	Estimated Value on Completion 12,000 source lines - FORTRAN
3	PREDICTED VALUE AS OF THIS DATE	Estimated Value on Completion 13,000 source lines - FORTRAN
4	RATIONALE FOR PREDICTION	Estimate developed last month indicated increase due to lack of progress in CPC 2 of CPCI RDRSWTC
5	CONSTRAINTS AS OF THIS DATE	System Configuration: No Change from Prediction Set Month 3 Workload: Same as Prediction Set Month 5 and R-7
6	VALUE ESTIMATED THIS MONITORING PERIOD	
7	COMMENTS (If Significant Difference Between Items 3 and 6)	
8	OTHER COMMENTS	

Figure C-1. Prediction Set Form

object word, an expansion ratio of 1:5 would be used. This means that for every FORTRAN source statement there would be 5 object instructions, and with the 1:1 instruction to word ratio, 5 words of memory required. It has never been clear as to what this ratio was based on; that is, whether the instruction mix was similar to that required for radar switching. However, the contractor assured the PO that COMMENT lines were excluded from the count of source code used to derive the ratio.

The second assumption that has been made is that the code would be of "medium" complexity. It is also not clear what this means. Many estimating algorithms break productivity into HARD, MEDIUM, and EASY difficulty groups. The S&TO has rightly made the decision to try to back-fit actual code production into actual resources used in order to estimate the difficulty.

Based upon 12,000 lines of source code, all of which are to be delivered, the memory requirement to support the CPCI would be 60,000 words of storage. The memory budget for CPCI RDRSWTC is currently 64K words, not including data.

The initial estimates for the 15 CPCs were based on historical data from a previous system. Adjustments have been made to account for different word length and instruction length; however, in view of the fact that all coding is to be done in FORTRAN, estimated resources were based on prior corporate history. One thing that has bothered the S&TO is that the function of TASKING CALIBRATION within CPCI RDRSWTC is not clearly defined. This, along with the prior behind schedule performance in the conduct of reviews, has resulted in the previous increase in estimated code count of 1,000 source lines. The S&TO is looking for the completed coding and compilation of four modules, or about 800 lines of code. Module sizes have been running larger than the 100 lines established as a goal, but the contractor has been firm in his view that modules of 100 lines cause excess record keeping and inefficient coding.

3. Receive Data or Request Update.

The S&TO has received the following data items as monthly inputs:

- a. DI-S-30568 - Computer Program Sizing and Timing Data, and
- b. DI-F-6000B - Cost Performance Report (CPR).

DI-S-30568 still indicates that CPCI RDRSWTC is estimated at 12,000 lines of source code. However, there was a statement from the contractor indicating that:

...due to the continued definition of the degree of complexity of CPCI RDRSWTC, it has been necessary to modify the approach for the coding of CPC #2.

CPC #2 contains the four modules that were due to be coded during the previous month. The question that the S&TO immediately asked was, "How much code was developed last month?" The contractor promised to return with the answer.

Looking at the Cost Performance Report, the Cost Account reflecting the budgets for CPC #2 indicated 3 manmonths for CODE & CHECKOUT and TEST & INTEGRATION. This did not seem to correlate with the revised CPDP that showed only 30 manmonths for the CODE & CHECKOUT and TEST & INTEGRATION of all 15 CPCs, with a total of 12,000 lines of code. Taking the total 60 manmonths and checking back, the S&TO found that the contractor had allocated 4 manmonths for each CPC to go from ANALYSIS through TEST & INTEGRATION. This was based on an estimated productivity of 166 source lines per manmonth, but this was the resource for the initial estimate of 10,000 lines. Code count has increased by 2,000 lines, with resources remaining the same. Looking at actual resources expended in the analysis and design phases of CPCI RDRSWTC, 50% of the resources (30MM/60MM) have been expended. This leaves only 20% for CODE & CHECKOUT and 30% for TEST & INTEGRATION. With the CPR indicating 3 manmonths for CODE & CHECKOUT, that leaves only 9 manmonths for the other 14 CPCs that contain about 11,200 lines of code. If the 20% factor is anywhere near accurate, this

means that the resources for 11,200 lines of code would be 45 manmonths (9/.2), that would yield a required overall productivity of 248 lines per manmonth. The S&TO updated his Preliminary Data File by completing a Prediction Set form based on the above information.

4. Perform Analysis

Based on the above, the S&TO went back to the software engineer in the PO and the Business Manager, and asked the following questions. The answers, that took one week to obtain, are shown with the question:

Q: Is the analysis and design complete for CPCI RDRSWTC?

A: Yes.

Q: How many modules and associated code were to have been developed and compiled as of the last reporting period?

A: 800 lines.

Q: How much has been completed?

A: 200 lines.

Q: Is the analysis and design complete for the entire CPCI?

A: Yes.

Q: 50% of the resources have been expended in ANALYSIS & DESIGN alone. How much of the CODE & CHECKOUT budget has been expended?

A: 1.5 manmonths.

At this point the S&TO is greatly concerned. First, what appeared to originally be a reasonable budget for CODE & CHECKOUT of 12,000 lines of code (12 manmonths, that is 20% of the entire budget of 60 manmonths), now appears to be in trouble. 12.5% of the budget has been expended to develop only 1.6% of the total code (200/12,000). The S&TO reviews the established factors for software development and finds that the widely used split is:

- 40% Analysis & Design,
- 20% Code & Checkout, and
- 40% Test & Integration.

These factors agree fairly well with the estimates of the resources for CPCI RDRSWTC:

- 50% Design & Analysis (a little heavy),
- 20% Code & Checkout, and
- 30% Test & Integration.

Even the total resources of 60 manmonths for 12,000 lines of code, that gives 200 lines of delivered and checked-out code per manmonth, is within the range of medium complexity code.

The S&TO now is convinced that one of two things has happened. First, the complexity of the code is greater than anticipated, as shown by heavy actuals in Design & Analysis (50% of budget) and the high initial core utilization of 93% (60K/64K); and second, the lack of progress in delivered code with high resource consumption shows there is every probability that core will be exceeded. This last observation was confirmed when the contractor acknowledged that 500 lines of code were thrown away during the month.

5. Prepare Report

The thrust of the S&TO report to the Program Manager is that there appears to be a serious problem, based on performance to date, with the size of CPCI RDRSWTC. From experience, the S&TO knows that the lack of progress in the development of software is very often the forerunner of increased size. As of this report he has no estimate of what the eventual size will be, but he strongly recommends a SIZING AND TIMING STUDY UPDATE be conducted.

6. Update Data File

The Prediction Set form is updated to note that the estimate of 13,000 lines of code is highly suspect. In block 7, the S&TO notes that there has been very little progress in the coding of CPCI RDRSWTC.

7. Corrective Action

The conduct of an updated sizing and timing study for CPCI RDRSWTC will be undertaken.

TAB D PROPOSED REVISION OF DID (DI-S-30568)

This Tab contains a proposed revision of the Data Item Description (DID) entitled, Computer Program Timing and Sizing Data (DI-S-30568).

Computer Program Timing and Sizing Data (DI-S-30568)	D-2
Proposed Revision of DID	D-3

DATA ITEM DESCRIPTION		2 IDENTIFICATION NO.	
		AGENCY	NUMBER
1 TITLE Computer Program Timing and Sizing Data		USAF	DI-S-30568
3 DESCRIPTION PURPOSE This DID is used to obtain both estimated and actual computer program memory size requirements, computer program timing requirements and Computer Program Configuration Item (CPCI) interface data.		4 APPROVAL DATE 14 July 1976	
		5 OFFICE OF PRIMARY RESPONSIBILITY AFSC	
		6 DDC REQUIRED	
		8 APPROVAL LIMITATION	
7 APPLICATION INTERRELATIONSHIP This DID is designed for use in conjunction with the Computer Program Development Specification DI-E-30139, Computer Program Product Specification DI-E-30140 and Common Data Base Design Specification DI-E-30144. This DID, along with the above mentioned Specifications, apply to all Computer Program Configuration Items (CPCIs).		9 REFERENCE: Mandatory # 100-101 AFR 800-14, VOL II, dated 26 Sep 75	
Formerly: DS-3913-ASD		MCSL NUMBER 5	
10 PREPARATION INSTRUCTIONS 1. <u>General Requirements.</u> The Timing and Sizing Data shall describe in detail the CPCI timing data, memory utilization data and interface data. However, this DID shall not unnecessarily duplicate descriptive material presented in other documents. 2. <u>Detailed Requirements.</u> For convenience in describing the minimum essential content, the following paragraphs show a normal format for presentation of the material in the following description, paragraph headings and numbers indicate the general nature of the topic, and are minimum mandatory requirements. a. <u>Section 1 - Scope.</u> This section shall introduce the document and summarize the interface conventions used. b. <u>Section 2 - Applicable Documents.</u> This section shall contain references to the appropriate Computer Program Product Specification, Computer Program Development Specification, Common Data Base Design Specification and any additional documents that apply to the design or use of the Timing and Sizing Data. c. <u>Paragraph 3 - Interface Drawings.</u> This paragraph shall completely describe the interface. Functional interfaces between CPCIs within a system shall be identified in terms of specific input and output data, data rates, message formats, message contents, data units and accuracies, and operational limits. The interface between CPCIs, the computers, and the associated equipment shall be defined in terms of such relevant characteristics as memory size, word size, process and operational times, interrupt capabilities, inputs and outputs, buffers and special capabilities.			

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PROPOSED REVISION OF DID
COMPUTER PROGRAM TIMING AND SIZING DATA - DI-S-30568

PROPOSED CHANGES AND REVISIONS ARE UNDERLINED.

<u>BLOCK</u>	<u>PROPOSED BLOCK CONTENT</u>
1.	Computer Program <u>Sizing and Timing Data</u>
2.	USAF DI-S-30568 <u>A</u>
3.	This DID is used to obtain both estimated and actual computer program memory size requirements, computer program timing requirements and Computer Program Configuration Item (CPCI) interface data. <u>In addition, the data is correlated with the same data provided by other contract deliverable DIDs to insure that any changes or revisions are reflected in all documents.</u>
4.	No Change. Blank.
5.	No Change. Blank.
6.	No Change. Blank.
7.	This DID is designed for use in conjunction with the Computer Program Development Specification DI-E-30139, Computer Program Product Specification, DI-E-30140, and Common Data Base Design Specification, DI-E-30144, and Computer Program Development Plan (CPDP), DI-S-30567A. <u>In addition, if the requirements of the Cost/Schedule Control Systems Criteria (C/SCSC) are invoked, generated cost and performance data shall be traceable from required C/SCSC reports to reports generated under this DID. This DID, along with the above mentioned specifications and development plan, applies to all Computer Program Configuration Items (CPCIs).</u>
8.	No Change. Blank.
9.	No Change. AFR 800-14, Vol II, dated 26 September 1975.
10.	<ol style="list-style-type: none">1. General Requirements. <u>The sizing and timing data shall describe in detail the CPCI, CPC, and module timing data, memory utilization data, manpower resource data, schedule data and interface data. Applicable data submitted in compliance with other DIDs shall be transferred directly to the appropriate format prescribed by this DID.</u>2. Detailed Requirements. <u>The following paragraphs show the normal format for presentation of the minimum required material.</u>

PROPOSED REVISION OF DID
COMPUTER PROGRAM SIZING AND TIMING DATA - DI-S-30568

PROPOSED CHANGES AND REVISIONS ARE UNDERLINED.

<u>BLOCK</u>	<u>PROPOSED BLOCK CONTENT</u>
10.	<div><div>2.</div><div><div>a.</div><div>Section 1 - Scope. This section shall introduce the document and summarize the interface conventions used. <u>Special emphasis shall be placed on describing how all the applicable contract documents dealing with software sizing and timing are presented in this deliverable.</u></div></div><div><div>b.</div><div>Section 2 - Applicable Documents. <u>This section shall list all (underline all) related contractual documents dealing with computer program sizing and timing. The display of these documents shall be in a form similar to Format No. 1 attached herein. Not only shall the document nomenclature be presented, but also the specific paragraph, the date of the document, approval status, and whether the type of information presented is different from that of the prior document.</u></div></div><div><div>c.</div><div>Section 3 - Computer Program Breakdown. This section shall list all computer products indicating the structural relationships among CPCIs, CPCs, and modules. In addition, any computer programs not being developed or processed under this contract, but which could be resident in the embedded computer system, such as system text software, shall be described so as to include memory budget for all programs and associated data. Computer programs shall be displayed in a form similar to Format No. 2 attached herein. It should be noted that resource data, that is required by management systems such as the Cost/Schedule Control Systems (C/SCSC), shall be included. Resource data shall be the most current data that has been provided by the applicable Cost Performance Report, Cost Schedule Status Report, or other documents.</div></div><div><div>d.</div><div>Section 4 - Interface Drawings. This section shall completely describe the interfaces. Functional interfaces between CPCIs within a system shall be identified in terms of specific input and output data, data rates, message formats, message contents, data units, including accuracies and operational limits. The interfaces between CPCIs, the computers, and the associated equipment shall be defined in terms of such relevant characteristics as memory size, word size, process and operational times, interrupt capabilities, inputs and outputs, buffers and special capabilities.</div></div></div>

PROPOSED REVISION OF DID
COMPUTER PROGRAM SIZING AND TIMING DATA - DI-S-30568

PROPOSED CHANGES AND REVISIONS ARE UNDERLINED.

<u>BLOCK</u>	<u>PROPOSED BLOCK CONTENT</u>
10.	
2.	
e.	<u>Section 5 - Measurement Conventions. This section shall provide the conventions used to generate the data displayed in Format No. 2. For example, the specific algorithms used to calculate reserve core, per cent of core utilization, and the basis for initial module estimates, sequencing and maximum run-times. DO NOT use explanations such as "Engineering Judgement" or "Similar Systems" without further explanation. Each category of measurement convention shall be identified by a reference code, such as "C1 = spare core convention," or, "E1 = estimated code count based upon module ABC of system XYZ." Reference codes shall be used in Format No. 2. Definitions shall be provided for all terms such as "source code" (with or without comments?), which may be subject to misinterpretation.</u>

FORMAT NO. 1

COMPUTER PROGRAM SIZING AND TIMING DATA - DI-S-30568A (DRAFT)

RELATED DOCUMENTS

DOCUMENT NAME	CDRL NO.	ISSUE DATE & REVISION	DESCRIPTION OF TYPE OF SIZING & TIMING INFORMATION	REFERENCE PARAGRAPH	HAS DATA CHANGED SINCE LAST REPORT?

FORMAT 2a				
COMPUTER PROGRAM SIZING AND TIMING DATA - DI-S-30568A				
COMPUTER PROGRAM BREAKDOWN - CPCI Level (Use a separate sheet for each CPCI)				
CPCI NUMBER:				
WBS ELEMENT NAME:				
RESPONSIBLE ORGANIZATION:				
SIZE DATA				
TYPE LANGUAGE	INITIAL ESTIMATE		CURRENT ESTIMATE	
	SOURCE	OBJECT WORDS	SOURCE	OBJECT WORDS
EXISTING CODE				
CONVERSION CODE				
NEW CODE				
TOTAL CODE				
RESOURCE REQUIREMENTS				
ESTIMATED EFFORT IN MANMONTHS	INITIAL ESTIMATE	REVISED ESTIMATE	ACTUALS TO DATE AS OF	
ANALYSIS				
DESIGN				
CODE & CHECKOUT				
TEST & INTEGRATION				
INSTALLATION				
OPERATION & SUPPORT				
DOCUMENTATION				
OTHER				
TOTAL MANMONTHS				
MEMORY BUDGETS				
ITEM	BUDGET	CURRENT ESTIMATE		
Available memory, total	words, 100%	words,		
Budget for this CPCI	words, %	words,		
Data for this CPCI	words, %	words,		
Reserve for program changes	words, %	words,		
Reserve for estimating error	words, %	words,		
Reserve for additional data	words, %	words,		

<p align="center">FORMAT 2a</p> <p align="center">COMPUTER PROGRAM SIZING AND TIMING DATA - DI-S-30568A</p>		
TIMING BUDGET		
	BUDGET	CURRENT ESTIMATE
MAXIMUM EXECUTION TIME:		
RELATED CPCs (List)		
ESTIMATING CONVENTIONS		
ESTIMATE KEY	PARAMETER	DEFINITION

FORM-1 2b COMPUTER PROGRAM SIZING AND TIMING DATA - DI-S-30568A				
COMPUTER PROGRAM BREAKDOWN - CPCI Level (Use a separate sheet for each CPC)				
PARENT CPCI IDENTIFICATION:				
SIZE DATA				
TYPE LANGUAGE	INITIAL ESTIMATE		CURRENT ESTIMATE	
	SOURCE	OBJECT WORDS	SOURCE	OBJECT WORDS
EXISTING CODE				
CONVERSION CODE				
NEW CODE				
TOTAL CODE				
RESOURCE REQUIREMENTS				
ESTIMATED EFFORT IN MANMONTHS	INITIAL ESTIMATE	REVISED ESTIMATE	ACTUALS TO DATE AS OF	
ANALYSIS DESIGN CODE & CHECKOUT TEST & INTEGRATION INSTALLATION OPERATION & SUPPORT DOCUMENTATION OTHER				
TOTAL MANMONTHS				
TIMING BUDGET				
		BUDGET	CURRENT ESTIMATE	
MAXIMUM EXECUTION TIME:				
RELATED MODULES (List)				

Format 2c

COMPUTER PROGRAM SIZING AND TIMING DATA DI-S-30568A

COMPUTER PROGRAM BREAKDOWN - MODULE LEVEL

MODULE LISTING *	TOTAL CODE			EXECUTION TIME			MANMONTHS TO DATE	
	INITIAL ESTIMATE	REVISED ESTIMATE	ACTUALS TO DATE	INITIAL ESTIMATE	REVISED ESTIMATE	DEMON- STRATED	BUDGETED	ACTUAL
CPCI 1								
CPC 11								
MODULE 111								
MODULE 112								
MODULE 113								
CPC 12								
MODULE 121								
MODULE 122								
MODULE 123								
CPCI 2								
CPC 21								
MODULE 211								
MODULE 212								
MODULE 213								
CPC 22								
MODULE 221								
MODULE 222								
MODULE 223								
.								
.								
.								

* Listing is provided as an example.

TAB E FUTURE WORK SUGGESTIONS

The following suggestions for future work are presented for ESD/TOI consideration. The suggestions are directed towards using, updating, and improving the procedures presented in this handbook, for estimating computer system sizing and timing parameters.

1. Encourage the use of the handbook by ESD/TOI engineers and computer scientists.
2. Conduct training classes in the use of the handbook.
3. Establish an ESD/TOI repository of sizing and timing studies performed by Program Offices and ESD/TOI.
4. Establish the capability for converting the results of sizing and timing studies into a uniform accessible data base.
5. Based on the sizing and timing data acquired through the repository and data base, validate and expand the metrics and information presented in this volume of the handbook.
6. Ensure the continued viability of the handbook through subsequent enhancement of the scope of the procedures and techniques based on actual application.

REFERENCES

1. Frederic, Brad C., A Provisional Model for Estimating Computer Program Development Costs, Tecolote Research, Inc., Report No. TM-7, Rev. 1, August 1974.
2. Graver, C. A., et al., Cost Reporting Elements and Activity Cost Tradeoffs for Defense System Software - Study Results, General Research Corporation, Report No. ESD-TR-77-262, Vol. I, 11 May 1977. AD/A-053-020
3. Herd, J. , Postak, J. N., Russell, W. E., et al., Software Cost Estimation Study - Study Results - Final Report, Doty Associates, Inc., Report No. RADC-TR-77-220, Vol. I (with Errata), February 1977. AD/A-042-264
4. Kossiakoff, A., et al., DoD Weapon Systems Software Management Study, Johns Hopkins University Applied Physics Laboratory, APL/JHU SR 75-3, June 1975.
5. Walston, C. E., Felix, C. P., "A Method of Programming Measurement and Estimation," IBM Systems Journal, Vol. 16, No. 1, 1977, pp. 54-73.

ANNOTATED BIBLIOGRAPHY

This Annotated Bibliography presents abstracts of some of the more relevant documents cited in the Bibliography in Volume I of this handbook.

1. Beizer, Boris, Micro-Analysis of Computer System Performance, Van Nostrand Reinhold Company, New York, 1978.

Abstract

The author presents his subject with two main objectives. First, to discuss how performance analysis could be accomplished on a simple computer system or a segment of a large computer system. Second, to introduce techniques for accomplishing such analyses. Performance measures and parameters are discussed, followed by a presentation of an evaluation technique, which the author calls a first cut performance analysis. The approach encompasses some mini-max relationships that could prove of value when more accurate approaches could not be utilized due to the lack of adequate data. In addition, timing and systems analysis are also discussed.

Keywords

performance analysis, performance measures, techniques, timing

2. Bell, C. G., et al., Computer Engineering; A DEC View of Hardware Systems Design, Digital Press, Bedford, Mass., September 1978.

Abstract

The book presents a case study approach that examines thirty Digital Equipment Corporation (DEC) computers developed by the company over the past twenty years. Various aspects of DEC hardware designs are discussed, and

improvements over the years in access time, memory size, transfer rates, performance, etc., are illustrated in graphs. The authors state that performance parameters are a combination of architecture (the instruction set processor), the hardware implementation, and the resources (the processor-memory-switch) being acted on by the programs (the use). In addition, they comment that simplistic hardware measures, such as instruction times, can be used to characterize machine performance for many cases. However, the ultimate performance has to be based on actual use parameters, otherwise there is no way to correlate the primitive hardware measures to real performance.

Keywords

Access Time, architecture, hardware measurements, memory size, performance, transfer rates

3. Bourdon, Gerard A., Duquette, Joseph A., A Computerized Model for Estimating Software Life-Cycle Costs (Model Concept), ESD Hanscom AFB, Report No. ESD-TR-77-253, Vol. I, April 1978. AD/A-053-937

Abstract

This report is the first volume of a series of reports on the development of a computerized model for estimating software life-cycle costs. This volume deals with the basic concepts of the model. The report defines the models basic stages, the methodologies employed, and the desired features. The report contains information on operating the model by manual methods. The first stage of the model, sizing, transforms software functional requirements into estimates of computer program size. It relies on results obtained by Doty Associates, Inc. (DAI) in their software cost estimation study for RADC; e.g., relating software memory size (words of object code) to software characteristics (application, number of major functions) and hardware parameters (word size, processor cycle time). Similarly, the other stages of the model (manpower, schedule, manloading, and cost) are also derivations from previous results obtained by DAI as

well as L. H. Putnam (life-cycle manloading). The importance of software sizing in estimating project resource requirements is evident in this model.

Keywords

cost, estimates, functions, LCC, manloading, modeling, scheduling, sizing, software

4. Boyse, J. W., Irani, K. B., Uppal, I. S., et al., Study of Information in Multiple-Computer and Multiple-Console Data Processing Systems, Michigan University, Annual Report #4, Report No. RADC-TR-071-160, August 1971. AD/A-729-194

Abstract

A portion of this report discusses the application of operations research techniques to the general problem of optimization of multiprogrammed, multiprocessor computer systems. The analysis procedure itself is computerized. The paper is principally concerned with estimation and control of timing parameters through investigation of software module execution priorities, software/hardware tradeoffs, parallel processing, and storage hierarchies.

The mathematical model developed by the authors accommodates effects of user program behavior, operating system characteristics, and hardware performance. It can be employed as an investigation tool for analyzing computer systems in general or for detailed analysis of a particular system. The model could also be used in optimizing computer systems. According to the authors, the results of their model closely approximates those obtained from simulation models.

The model requires information on the user programs (including estimated size), storage device descriptions, and data traffic dependencies and architecture. Model output is system performance (mean program execution rates, queue lengths, CPU utilization).

The paper contains detailed consideration of topics such as task scheduling, data structures, and hardware characteristics. Full description of the model is contained in another paper (Analysis and Optimization of Multiprogrammed Computer Systems Using Storage Hierarchies, A.M. Woolf).

Keywords

configuration, hardware, memory, modeling, performance, real-time, software, storage, timing

5. Capps, L. R., Software Management and the Testing of Weapons Systems that Contain an Embedded Computer System, Defense Systems Management College, Student Report No. 75-2, November 1975. AD/A-026-556

Abstract

This report presents an overview of the Department of Defense Weapon System Software Management Program. Specifically, the program is examined from the point of view of the testing requirements associated with the development of weapon systems that contain embedded computer systems. The thrust, as presented in the report, is the evolution from software development as an art to software development as a science.

Useful portions of the report deal with the attributes of embedded systems, a model of the system development phases, and an excellent description of the software verification process.

Keywords

embedded computer systems, management, modeling, software, testing, verification, weapon systems

6. Carey, L. J., Hirschfield, G. A., Tucker, A. E., et al., Survey of Software Techniques - Spaceborne Software Systems Study, System Development Corporation, Report No. SSD-TR-67-11, Vol. IV, January 1967. AD-807-400

Abstract

This report reviews software and the software development process as they apply to satellite systems. Among other things, it briefly discusses sizing and timing tradeoff techniques; e.g., methods by which more software or data storage space is given up in order to achieve higher processing speed. An algorithm is given for allocation of storage space, given subprogram size and operating time. Methods for estimating time parameters during program testing are outlined.

Keywords

memory, module, procedures, real-time, sizing, software, storage, timing

7. Drummond, Mansford E., Jr., Evaluation and Measurement Techniques for Digital Computer Systems, Prentice Hall, Inc., Englewood Cliffs, N.J., 1973.

Abstract

The book discusses the evaluation of CPU performance and system performance, simulation techniques, systems analysis techniques, programmed measurement techniques, as well as instrumented measurement techniques. The author also discusses how and when to use various evaluation techniques. Of primary relevance to this handbook are the discussions of systems analysis techniques that are identified as the simpler techniques that involve determination of throughput and/or response time attributes.

Keywords

performance evaluation, system performance, systems analysis, techniques

8. Embedded Computer Resources and the DSARC Process - A Guidebook, Office of the Secretary of Defense, 1977. AD/A-046-398

Abstract

This guidebook covers salient embedded computer resource issues in the context of the Defense System Acquisition Review Council (DSARC) process. The guidebook is divided into five sections: (1) the first section discusses general DSARC issues and provides guidelines to determine adequacy of computer resource utilization and planning. The section also provides a list of questions to guide OSD personnel in their evaluation of embedded computer resources at each DSARC meeting; (2) the second section discusses sensitivity data and relationships and reviews some twenty-five factors and their relationship to productivity; (3) the third section discusses program inquiry questions and suggests several replies that cover general background, software estimating, and programming practices; (4) the fourth section provides guidelines for software estimating; and (5) the final section contains a list of reference documents covering policy, practice, and procedures.

Keywords

acquisition, cost, embedded, estimates, procedures, productivity, regulations

9. Ferrari, Domenica, Computer Systems Performance Evaluation, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1978.

Abstract

Developed as a course book for computer science seniors and first-year graduate students, the author discusses performance evaluation of computer systems from a macro-analysis approach, as well as from an overview of the subject matter. Techniques, viewpoints and approaches that the author considered as becoming more viable in the near future are presented. Measurement tools, analytic modeling and workload characteristics are

discussed, as are computer selection, performance improvement, and performance evaluation in computer system design. In addition, evaluation of program performance is also discussed. The author's treatment of the multitude of complexities and diversified views of the various aspects of computer system performance evaluations and its numerous parameters are of particular interest.

Keywords

analytic modeling, computer selection, computer system, measurement tools, performance evaluation, performance improvement, program performance evaluation, workload characteristics

10. Flynn, Michael J., Studies in the Organization of Computer Systems, 1977 Progress Summary, Digital Systems Laboratory, Stanford University Technical Note No. 121, November 1977.

This project report discusses various research activities into theoretical and practical methods for categorization, analysis and synthesis of computer systems. Of particular interest is their analytical modeling of certain types of parallel machine performance. Their model distinguished the differences between logical parallelism in terms of available processes and the physical parallelism (the p processors) available in a computer organization. This analysis demonstrated the dependency of performance bounds on both the computation being executed and the computer architecture. The report notes that the analysis demonstrated that necessary and sufficient conditions for a maximum attainable speedup of p parallel processors over a uniprocessor would be sped up less than $p/\ln p$ as long as the logical parallelism exceeded the number of physical processors available in the program. The conditions that establish validity are based on certain artifacts of control in parallel programs. The author states that their results were consistent with Mr. D. Ruck's study at the University of Illinois.

Keywords

modeling, parallel processors, performance, uniprocessors

11. Graver, C. A., et al., Cost Reporting Elements and Activity Cost Trade-offs for Defense System Software - Study Results, General Research Corporation, Report No. ESD-TR-77-262, Vol. I, 11 May 1977. AD/A-053-020

Abstract

This paper surveys software cost estimating techniques as they are applicable to the acquisition cycle. A "process model of software development" is proposed that is based on interviews with Air Force SPO's and on AFR 800-14. The resulting model is not fully in accord with AFR 800-14 but may be a more useful basis for software size estimating in that it recognizes the interdependencies among the development phases. Detailed descriptions of activities in each phase are given.

This paper advocates use of object code size as a metric for some phases of software acquisition and source code for others (most importantly, the coding and checkout phase). Effects of language and hardware specifications are recognized. Expansion ratios for COBOL, JOVIAL, and FORTRAN are given for several software packages on various computers.

The report describes in very summary form a software sizing procedure. It involves categorizing required software by type, considering software complexity, and applying size estimating techniques (none included).

Keywords

acquisition, complexity, cost, cost estimating relationships, estimates, modeling, procedures, productivity, regulations, schedule, sizing, software, techniques

12. Hagan, S. R., Knight, C. W., Air Force Guide for Monitoring and Reporting Software Development Status, Mitre Corporation, Report No. ESD-TR-75-85, Vol. I, September 1975. AD/A-016-488

Abstract

This guidebook provides information for managers and technical personnel engaged in, or planning for, the monitoring and reporting of the technical status of a software development project. It reflects the acquisition life-cycle as presented in AFR 800-2.

Tools for monitoring development are reviewed. A statement of new software methodologies and their effect on management visibility is also presented.

Keywords

acquisition, monitoring, performance, regulations, software

13. Halstead, Maurice, H., Elements of Software Science, Elsevier North-Holland, Inc., New York, 1977.

Abstract

This study presents an approach to software sizing based on the application of principles of natural science. It attempts to relate the process of producing computer instructions (and, more broadly, language prose) to much more basic processes of human cognition. For each hypothesis posed, the paper describes carefully designed empirical studies of the author or others that support it. A number of factors are described that, if accepted, provide a comprehensive foundation for understanding the process of software development and how it is affected by such things as programmer capability, language employed, and nature of the problem to be solved by computer.

The author argues, for example, that a lower bound is established for the effort to prepare a particular software algorithm only if the problem is

well-stated (and well-understood by the programmer), the programmer is fluent in the language employed, and the programmer applies full mental concentration to the effort. If any of these conditions is not fully met, greater effort is required to successfully develop the software. One dimension of effort is size of the software.

Judging from the literature, Halstead's work is not now widely familiar or accepted. It seems probable, however, that this approach to understanding the process of software development, because of its basis in fundamental human reasoning abilities, will prove to be far more powerful than current empirical methods.

Keywords

empirical studies, estimates, instructions, languages, modeling, procedures, programmer capability, sizing, software, techniques

14. Herd, J. H., Postak, J. N., Russell, W. E., Stewart, K. R., Software Cost Estimation Study - Study Results-Final Report, Doty Associates, Inc., Report No. RADC-TR-77-220, Vol. I (with Errata), February 1977. AD/A-042-264

Doty, D. L., Nelson, P. J., Stewart, K. R., Software Cost Estimation Study - Guidelines for Improved Software Cost Estimating, Doty Associates, Inc., Report No. RADC-TR-77-220, Vol. II (with Errata), February 1977. AD/A-044-609

Abstract

This report discusses general software size estimating procedures and requirements. It emphasizes the importance of careful initial design and advocates the preparation of a software work breakdown structure to reduce estimating errors.

Several size estimating techniques are included that were statistically developed from data in the literature and, based on their correlation coefficients, are not particularly precise estimators. Two estimating

relationships give number of lines of source code as a function of software functions, hardware characteristics, and application type. Another estimator relates required core size to software and processor characteristics and type of application.

For analogy sizing, an estimator is developed that relates software size of a new program to that of an analogous program, the number of major types of functions to be performed by the new software, and the number of functions performed by the analogous program. Also, an algorithm for converting from object code estimates to source code estimates is given as a function of the expansion ratio and the language mix.

Keywords

cost, cost estimating relationships, estimates, hardware, memory, procedures, productivity, schedule, sizing, software, techniques

15. Information Processing/Data Automation Implications of Air Force Command and Control Requirements in the 1980s (CCIP-85) (U), Volume IV, Technology Trends - Software, SAMSO TR 72-122, October 1973. AD-919-267

Abstract

The study report is one of several reports prepared in the CCIP-85 study effort. The objective of the CCIP-85 study was to examine the functions to be performed by future Command and Control systems and assess what new functions must be performed by the computer software and hardware. Volume IV of the study report discusses requirements, future capabilities potential, and associated potential problem areas. The report also outlines promising R&D strategies to resolve the differences between future Command and Control requirements and future software technology.

Keywords

Command and Control, future capabilities, hardware, software

16. Johnson, L. A., et al., "Automated Analysis of System Specifications," Second U.S. Army Software Symposium (Proceedings), U.S. Army Computer Systems Command, Williamsburg, Va., 25-27 October 1978, pp. 235-258.

Abstract

This paper describes an automated Air Force technique for qualifying system requirements, where system is defined broadly as a collection of equipment, personnel resources, capabilities and techniques that together perform an operational role. It discusses, among other things, the derivation of discrete, non-overlapping requirements and the structuring of information requirements hierarchies. The methodology provides for linking system performance requirements to specific designs, and the paper notes that relationships exist that can provide a link between requirements engineering activities and subsequent implementing engineering, since such requirements can be traced from functional-performance specifications to development specifications to product specifications and system test activities during the later phases of the system acquisition.

Keywords

acquisition, configuration, hardware, modeling, quality, performance, software engineering, systems

17. Kossiakoff, A., et al., DoD Weapon Systems Software Management Study, Johns Hopkins University Applied Physics Laboratory, APL/JHU SR 75-3, June 1975.

Abstract

This report presents the results of a study conducted by the Applied Physics Laboratory of the Johns Hopkins University in conjunction with the MITRE Corporation. The purpose of the study and the resultant report centered on the problems associated with the acquisition of weapon systems containing and/or driven by extensive software programs. Seventeen recommendations are provided that, if implemented, could be of great value in reducing cost and schedule problems associated with large systems.

Two useful features provided by the report are: 1) system configuration descriptions and associated histories of selected weapon systems, and 2) discussions by several major software development organizations as to the problems of system development and recommended solutions. The major problem is indicated to be the lack of system definition as supported by initial requirement analysis.

Keywords

acquisition, procedures, requirements analysis, system configurations, software engineering, system developments, weapon systems

18. Kosy, Donald W., Air Force Command and Control Information Processing in the 1980s: Trends in Software Technology, The Rand Corporation, Report No. R-1012-PR, Vol. I, June 1974. AD/A-017-128

Abstract

This report discusses software trends in the Air Force Command and Control systems in the 1970's and 1980's. The state-of-the-art of software technology, as it existed in 1972, is discussed and forecasts changes in technology over the next fifteen years. Comparisons are made between projected Air Force requirements and software technology. Future improved software qualitative requirements are considered to be vital in Air Force Command and Control systems. The software technology forecasts were projected based on historical developments and technological trends. It was noted that, unlike hardware forecasting, software forecasting was difficult because there was no firm data base from which to project. However, projections were made in the area of software functions and methods of design, production and validation. Finally, future software technology capabilities estimates were compared with the projected software requirements.

Keywords

C³, hardware, language sizing, software, software development, trends

19. Lehman, John H., Thayer, Richard H., Software Engineering Project Management: A Survey Concerning U.S. Aerospace Industry Management of Software Development Projects (Interim Report), Sacramento Air Logistics Center/ACD, Report No. ACD TR-77-02, November 1977. AD/A-050-802

Abstract

This paper gives certain summary findings from a survey of 18 aerospace companies engaged in software development efforts. Although not directly relevant to sizing and timing estimation, the report does provide information on the environment in which past software development efforts were conducted. For example, approximately equal numbers of the projects in the sample began with little or no specifications, moderately complete specifications, or highly detailed specifications. The percentage of specification rewrite required during the project was directly proportional to the degree of initial specification. A number of constraints were placed on various development efforts, including specified hardware, storage limitations, speed requirements, and budget and schedule limits. Certain software development management practices are also summarized.

Keywords

cost, estimates, hardware, procedures, quality, schedule, software, software development, specifications

20. Martin, James, Design of Real-Time Computer Systems, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1967.

Abstract

This book, one of the Prentice-Hall Series in Automatic Computation, is an excellent treatise on the design of real-time systems. Of particular utility are the chapters that discuss estimating program size, system timing, and core storage requirements. These chapters provide sets of procedures that are generally directed toward the end of including all factors in the estimating process that may cause the greatest penalty if ignored. In addition, the book discusses the problems of design of

real-time systems, calculations and estimating techniques, and reasons for incorrect estimates.

Keywords

C³, estimating, real-time, reliability, sizing, storage, techniques, timing

21. Matick, Richard, Computer Storage Systems & Technology, John Wiley & Sons, Inc., New York, 1977.

Abstract

This book discusses memory and storage technology. A history of the change in size, timing elements, and types of storage systems is explored. The uses of primary and secondary memory system are discussed. Fundamental principles of memory and storage parameters and architecture are presented. Random access methods, magnetic characteristics of recording medium, sequential access methods, direct access methods, file organization, data structures, memory hierarchies, and virtual memory are discussed in detail.

Keywords

configuration, hardware, memory, performance, sizing, storage

22. Navarro, Aaron B., Romanczuk, Ronald J., Imbedded Software Monitors and Data Collection - Design and Implementation, PRC Information Sciences Company, Report No. RADC-TR-74-217, Vol. I, September 1974. AD-787-672

Abstract

This paper describes a software monitoring procedure that is used to measure timing parameters (e.g., CPU time, I/O time) of program modules. The information could assist in determining frequency routines, time and storage requirements. Regressions were run on data collected using the

monitoring system on a data management system software package. Equations for record retrieval I/O time, CPU time, and number of reads were derived as functions of file size, page size, and number of buffers used.

Keywords

estimates, hardware, modeling, module, performance, sizing, software, techniques, timing

23. Neil, George, Software Acquisition Management Guidebook: Reviews and Audits, System Development Corporation, Report No. ESD-TR-78-117, November 1977. AD/A-052-567

Abstract

This report combines existing guidance regarding reviews and audits currently contained in a number of different official documents and narrows the focus of editing guidance to those problems inherent in software acquisition management. Engineering design reviews and configuration management audits are broken down into: (1) materials to be reviewed, (2) requirements, and (3) post-review activities.

The section on reviews and audits problem areas identifies some of the more common problems created by improper implementation of reviews and audits requirements. In addition, it discusses how engineering design reviews can be used to prevent other common and serious problems.

Keywords

acquisition, audits, design configurations, management, performance, regulations, requirements, reviews, software

24. Operational Software Management and Development for U.S. Air Force Computer Systems, National Academy of Sciences, National Research Council, Air Force Studies Board, Washington, D.C., 1977.

Abstract

The report presents the results of a 1976 Air Force Studies Board study that was concerned with the operational management and development primarily during the acquisition life-cycle of U.S. Air Force embedded computer resources. The study examined management approaches as applied in 1976 and suggests several approaches that the Air Force might employ to develop operational software for Embedded Computer Systems (ECS). The first problem cited was that detail requirements, especially extreme conditions and collateral tasks, are not delineated in the Required Operational Capability (ROC) documents, the Program Management Directive (PMD) or even the System Specification. As a result of these inadequacies, there is subsequent need to redesign and redo the software, not only throughout the acquisition life-cycle phases, but also into the Operations and Maintenance Phase. The second major problem cited pertained to the inadequate involvement of the user and the maintainer organizations throughout the entire acquisition life-cycle. The consequences are similar to those cited in the first problem area. The third problem area suggested by the study group was the one-of-a-kind philosophy of development. That is, each software development is considered a one time, specific development when actually there can be a considerable number of aspects of one development that could be beneficially applied to other developments. Also, there appears to be a distinct break in organizations' responsibilities, particularly between the acquisition life-cycle and the operations and support phase. The study group suggests an overlapping of the development organizations and the maintenance organization to develop a sense of continuity.

Keywords

acquisition life-cycle, embedded computer resources, embedded computer systems, management approaches, software development

25. Roberts, Alan J., Command and Control System Acquisition: Software Implications, User/Developer Interface, AIIE Conference on Electronic System Acquisition Management, Washington, D.C., 25-27 April 1979.

Abstract

This document was prepared for the AIIE Conference on Electronic System Acquisition Management. The author describes the distinguishing characteristics of C³ systems and the special problems they present to users and developers during the acquisition process. Various acquisition approaches are discussed that should improve the chances for a successful delivery of a C³ system with the required capabilities. The focus throughout is on two characteristics of C³ systems: software domination and user involvement. The conviction is expressed that one cannot produce adequate specifications or make satisfactory cost estimates without first actually performing some part of the task to be specified and estimated.

From the standpoint of sizing and timing, the author makes the observation that in practically every program, machine resources are overcommitted, both in response time and memory. Early estimates of hardware requirements are rarely applied, whereas funding limitations are imposed on software development. The author suggests that major fund commitments should not be made before appropriate hardware/software tradeoffs have been accomplished. Inadequacies of C³ hardware resources should be rectified by adding more hardware rather than by trying to revise the software. In weapons systems, however, where space and weight are specific constraints, a different approach may be required. Generally, the amount of spare memory capacity (25-30%) is used up in the development of the software. The author suggests that spare memory capacities of 100-200% might be considered to reduce many software development and subsequent maintenance problems. In addition, visibility and control of storage and response time should be maintained and should aid in resolving conflicts.

Keywords

acquisition, C3 systems, hardware requirements, memory, memory capacity, response time, software engineering, tradeoffs

26. Smith, Ronald L., Estimating Software Project Resource Requirements - Structured Programming Series, IBM Corporation, Report No. RADC-TR-74-300, Vol. XI, January 1975.

Abstract

This report deals with software development resource estimating in a structured programming environment. It reviews literature pertinent to software cost estimation and outlines some of the traditional procedures. A procedure (model) is discussed for estimating software resources on the basis of similar experience. The author states that size can be estimated on the basis of number of program modules times the average estimated module size.

Keywords

cost, estimates, module, procedures, productivity, schedule, size, software, systems

27. Svobodova, L., Computer Performance Measurement and Evaluation Methods: Analysis and Applications, Volume 2 in the Computer Design and Architecture Series, Elsevier Computer Science Library, American Elsevier Publishing Co., Inc., New York, 1976.

Abstract

This book develops an understanding of the problem of performance evaluation and shows how to analyze available techniques within this concept. The book is divided into two parts. The first part examines fundamental concepts and the second examines different tools and techniques in detail. Fundamental concepts include those elements of computer system performance: system workload measures, measurement, and analysis; control of system performance; and qualitative assessment of system performance.

Basic tools and techniques include system models, workload models, simulation, and measurement tools. To these must be added the question of measurability as discussed later in the book. System models encompass structure, function, analysis, and/or experimentation as a basis. Workload models include instruction mix, benchmarks, synthetic benchmarks, trace, probabilistic workload models, and interactive system drivers. Simulation is either stochastic or trace driven. Common measurement tools discussed are performance monitor, software and hardware monitors, and hybrid monitors. Measurement tools are discussed with emphasis on both their strengths and limitations.

Finally, the question of measurability is addressed separately. Such issues as privacy, environment, data acquisition, monitoring aids, and automatic control of system performance are addressed.

Keywords

benchmarks, complexity, estimating, hardware, measuring, memory, metrics, modeling, performance, productivity, sizing, storage, timing

28. Turn, R., Sine, B., Air Force Command and Control Information Processing in the 1980's: Trends in Hardware Technology, The RAND Corporation, Report No. R-1001-PR, Vol. V, October 1972. AD-907-626

Abstract

This report discusses hardware trends in the period of the 1970's into the 1980's. Sizing and timing constraints of hardware and software are reviewed and measured against expected changes in the 1980's.

It is stated that emphasis should be placed more on good Higher-Order Language (HOL) programming because sizing and timing will be less of a constraint and HOL tends to have fewer errors per function. The need for Machine Oriented Language (MOL) programming will be reduced since solutions to hardware problems are being implemented as part of the

hardware itself. Projections are presented for mass memory and timing performance into the 90's. A timing metric is discussed, and processor characteristics are described at length.

C³ is discussed by environmental class as being ground based, airborne, or spaceborne. Measures of performance for airborne software are presented.

Keywords

C³, environment, hardware, language, memory, metrics, performance, sizing, software, timing, trends

29. Welch, Terry A., "Analysis of Memory Hierarchies for Sequential Data Access," Computer, Vol. 12, No. 5, May 1979, pp. 19-26.

Abstract

This paper discusses techniques available for making size/speed tradeoffs between core and various external memory devices. An analytical model is developed that deals explicitly with the transfer of various quantities of data from external memory devices, each of which has a particular probability of access, size, transfer time, and storage cost. Analysis techniques can be applicable in the system design when these parameters can be estimated. Results of the analysis demonstrate the value of storage hierarchies from a cost-effectiveness standpoint.

Keywords

configuration, cost, hardware, memory, modeling, performance, real-time, sizing, software, storage, techniques, timing

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